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ASRB-NET

AGRONOMY

Agricultural Scientists Recruitment Board (ASRB)

VOLUME – 2

SIERRA INNOVATIONS

ASRB - NET (Agronomy)

IV UNIT Dryland Agronomy

Concept of dryland farming, dryland vs. Rainfed farming, history, development, significance, and constraints

Introduction

Dryland agronomy addresses agricultural practices in areas with limited and erratic rainfall, critical for India, where 60% of farmland depends on rainfed systems, contributing to food security (ICAR, 2023). This part explores the concepts of dryland and rainfed farming, their history, development, significance, and constraints.

Concept of Dryland Farming

Definition

Dryland farming is the cultivation of crops in regions with low rainfall (300–800 mm annually), minimal irrigation, and high moisture stress, relying on in-situ moisture conservation and drought-tolerant practices. It focuses on maximizing water use efficiency (WUE) and crop resilience in arid and semi-arid regions.

Key Features:

- Low, erratic rainfall (300–800 mm).
- No or limited irrigation (0–10% of water needs).
- Emphasis on moisture conservation (e.g., mulching, contour bunding).
- Crops: Millets, pulses, oilseeds (e.g., sorghum, groundnut).
- **Example**: Sorghum cultivation in Rajasthan's semi-arid zones relies on mulching to conserve moisture.

Importance

- **Food Security**: Supports 60% of India's farmland, producing 40% of food grains.
- **Livelihoods**: Sustains 68% of rural farmers in dryland areas.
- **Sustainability**: Promotes low-input, resilient practices.
- **Example**: Pearl millet in Gujarat's drylands yields 1–2 t/ha, supporting smallholder farmers.

Dryland Farming vs. Rainfed Farming

Definitions

- **Dryland Farming**: Agriculture in areas with <800 mm rainfall, minimal irrigation, and high moisture stress, focusing on conservation (e.g., Rajasthan's millets).
- **Rainfed Farming**: Agriculture dependent on rainfall (>800 mm), with occasional supplemental irrigation, covering sub-humid areas (e.g., Maharashtra's soybean).

Differences

Parameter	Dryland Farming	Rainfed Farming
Rainfall	300–800 mm	>800 mm
Irrigation	Minimal (0–10%)	Supplemental (10–30%)
Regions	Arid, semi-arid (Rajasthan)	Sub-humid (Vidarbha)
Crops	Millets, pulses	Rice, soybean, cotton
Practices	Mulching, tied ridging	Crop rotation, irrigation
Constraints	Drought, low fertility	Erratic rainfall, flooding

Applications

- **Dryland**: Focus on drought-tolerant crops (e.g., pearl millet), conservation (e.g., farm ponds).
- **Rainfed**: Supports high-yielding crops (e.g., rice), with irrigation backup.
- **Example**: Dryland sorghum in Karnataka uses mulching; rainfed rice in Odisha uses supplemental irrigation.

PYQ Analysis

1. What defines dryland farming?
   (A) High irrigation,
   (B) Low rainfall,
   (C) Flooded fields,
   (D) High fertility.

Answer: (B) Low rainfall.

Explanation: Dryland farming occurs in areas with 300–800 mm rainfall.

2. What distinguishes rainfed farming?
   (A) No irrigation,
   (B) Supplemental irrigation,
   (C) High rainfall,
   (D) Arid zones.

Answer: (B) Supplemental irrigation.

Explanation: Rainfed farming uses occasional irrigation in >800 mm rainfall areas.

3. Which crop is typical in dryland farming?
   (A) Rice, (B) Pearl millet,
   (C) Sugarcane, (D) Wheat.

Answer: (B) Pearl millet.

Explanation: Pearl millet is drought-tolerant, suited for drylands.

- **Trend**: PYQs focus on definitions, differences, and crop suitability, with recent emphasis on conservation practices.

History and Development of Dryland Agriculture in India

Historical Milestones

1. **Ancient Period (Pre-1000 CE)**:
   - **Practices**: Millets, pulses cultivated with contour bunding, farm ponds.
   - **Regions**: Deccan, Rajasthan used traditional water harvesting.
   - **Example**: *Krishi-Parashara* (400 BCE) described millet cultivation in drylands.
2. **Medieval Period (1000–1800 CE)**:
   - **Practices**: Tank irrigation, crop diversification (e.g., sorghum + pulses).
   - **Impact**: Sustained low-input agriculture in semi-arid zones.
   - **Example**: Tank systems in Tamil Nadu supported dryland crops.
3. **Colonial Period (1800–1947)**:
   - **Practices**: Introduction of groundnut, limited fertilizer use.
   - **Constraints**: Neglect of drylands, focus on irrigated areas.
   - **Example**: Groundnut cultivation expanded in Gujarat's drylands.
4. **Post-Independence (1947–1980)**:
   - **Developments**: Establishment of CRIDA (1985), dryland research programs.
   - **Practices**: Drought-tolerant varieties (e.g., *CSH 6* sorghum), contour bunding.
   - **Example**: CRIDA's research in Hyderabad improved millet yields.
5. **Green Revolution (1960s–1980s)**:
   - **Impact**: Focused on irrigated areas, but dryland research initiated (e.g., AICRPDA).
   - **Example**: Short-duration sorghum varieties introduced in Maharashtra.
6. **Modern Era (1990s–2024)**:
   - **Developments**: Watershed management, INM, precision agriculture.
   - **Policies**: National Rainfed Area Authority (NRAA, 2006), PMKSY (2015).
   - **Example**: Watershed programs in Rajasthan increased sorghum yields by 10–20%.

Development Initiatives

- **AICRPDA (1970)**: All India Coordinated Research Project on Dryland Agriculture, developed drought-tolerant varieties.
- **CRIDA (1985)**: Central Research Institute for Dryland Agriculture, focused on moisture conservation.
- **Watershed Programs**: PMKSY promotes farm ponds, check dams in drylands.
- **Example**: AICRPDA's *CSV 15* sorghum variety boosted yields in Karnataka.

PYQ Analysis

1. When was CRIDA established?
   (A) 1960, (B) 1970,
   (C) 1985, (D) 2000.

Answer: (C) 1985.

Explanation: CRIDA was founded to advance dryland research.

2. What was a focus of dryland agriculture post-independence?
   (A) Irrigation,
   (B) Drought-tolerant varieties,
   (C) High fertilizers,
   (D) Flood control.

Answer: (B) Drought-tolerant varieties.

Explanation: Varieties like *CSH 6* sorghum were developed.

3. Which policy supports dryland agriculture?
   (A) PMKSY,
   (B) MGNREGA,
   (C) Fasal Bima,
   (D) Soil Health Card.

Answer: (A) PMKSY.

Explanation: PMKSY promotes watershed management in drylands.

- **Trend**: PYQs focus on historical milestones, research initiatives, and policies, with recent emphasis on watershed programs.

Significance of Dryland Agriculture

Role in Indian Agriculture

- **Area Coverage**: 60% of India's farmland (80 Mha) is dryland, contributing 40% of food grains.
- **Crops**: Millets (50%), pulses (70%), oilseeds (60%) grown in drylands.
- **Livelihoods**: Supports 68% of rural farmers, especially smallholders.
- **Food Security**: Produces 30–40% of cereals, 70% of pulses.
- **Example**: Pearl millet in Rajasthan contributes 1–2 t/ha, feeding millions.

Economic and Social Benefits

- **Low-Input Systems**: Reduces costs (e.g., ₹5,000–10,000/ha vs. irrigated systems).
- **Resilience**: Drought-tolerant crops withstand climate variability.
- **Employment**: Supports rural economies in arid zones.
- **Example**: Groundnut in Gujarat's drylands generates ₹20,000–30,000/ha income.

Environmental Benefits

- **Sustainability**: Low water, fertilizer use reduces environmental impact.
- **Biodiversity**: Diverse crops (millets, pulses) preserve agro-biodiversity.
- **Example**: Intercropping sorghum + pigeonpea in Maharashtra enhances soil health.

PYQ Analysis

1. What is the significance of dryland agriculture?
   (A) High irrigation, (B) Food security,
   (C) Low yields, (D) Urban focus.

Answer: (B) Food security.

Explanation: Drylands produce 40% of India's food grains.

2. Which crop dominates dryland agriculture?
   (A) Rice, (B) Millets,
   (C) Sugarcane, (D) Wheat.

Answer: (B) Millets.

Explanation: Millets like pearl millet are suited for drylands.

3. What supports rural livelihoods in drylands?
   (A) High fertilizers,
   (B) Drought-tolerant crops,
   (C) Irrigation,
   (D) Urban markets.

Answer: (B) Drought-tolerant crops.

Explanation: Crops like sorghum sustain dryland farmers.

- **Trend**: PYQs focus on significance, crops, and socio-economic benefits, with recent emphasis on sustainability.

Constraints of Dryland Agriculture

Major Constraints

1. **Low and Erratic Rainfall**:
   - **Impact**: 300–800 mm rainfall, with 30–50% variability, reduces yields by 20–50%.
   - **Example**: Delayed monsoon in Rajasthan affects pearl millet sowing.
2. **Soil Degradation**:
   - **Impact**: Low SOM (<0.5%), poor fertility reduce productivity.
   - **Example**: Sandy soils in Gujarat limit nutrient retention.
3. **Drought Stress**:
   - **Impact**: Frequent droughts (1 in 3 years) cause 30–50% yield losses.
   - **Example**: 2015 drought in Maharashtra reduced sorghum yields by 40%.
4. **Limited Irrigation**:
   - **Impact**: <10% irrigation availability restricts crop choice.
   - **Example**: Rainfed millets dominate in Karnataka's drylands.
5. **Low Input Access**:
   - **Impact**: High costs of fertilizers, seeds limit adoption.
   - **Example**: Small farmers in Rajasthan use <50 kg/ha fertilizers.
6. **Socio-Economic Constraints**:
   - **Impact**: Low investment, poor market access reduce income.
   - **Example**: Groundnut farmers in Gujarat face price volatility.

Mitigation Strategies

- **Moisture Conservation**: Mulching, farm ponds increase WUE by 20–30%.
- **Drought-Tolerant Varieties**: *CSV 15* sorghum, *HHB 67* pearl millet resist drought.
- **INM**: FYM (10 t/ha), biofertilizers (*Azotobacter*) improve fertility.
- **Watershed Management**: Check dams, percolation tanks enhance water availability.
- **Policy Support**: PMKSY, RKVY provide subsidies for dryland inputs.
- **Example**: Farm ponds in Maharashtra's drylands increase sorghum yields by 15–20%.

Constraints Data

Constraint	Impact	Mitigation
Low Rainfall	20–50% yield loss	Farm ponds, mulching
Soil Degradation	Low fertility, SOM	INM, FYM, biofertilizers
Drought Stress	30–50% yield reduction	Drought-tolerant varieties
Limited Irrigation	Restricted crop choice	Rainwater harvesting
Low Input Access	Reduced productivity	Subsidies, RKVY

PYQ Analysis

1. What is a major constraint of dryland farming?
   (A) High rainfall,
   (B) Low rainfall,
   (C) Irrigation,
   (D) High fertility.

Answer: (B) Low rainfall.

Explanation: Low rainfall (300–800 mm) limits dryland productivity.

2. How is drought stress mitigated in drylands?
   (A) High irrigation,
   (B) Tolerant varieties,
   (C) Deep tillage,
   (D) No inputs.

Answer: (B) Tolerant varieties.

Explanation: Varieties like *HHB 67* pearl millet resist drought.

3. What limits input access in drylands?
   (A) Low cost, (B) High cost,
   (C) High rainfall, (D) Irrigation.

Answer: (B) High cost.

Explanation: High input costs restrict adoption by small farmers.

- **Trend**: PYQs focus on constraints and mitigation, with recent emphasis on conservation and policies.

Case Study: Dryland Farming in Rajasthan's Pearl Millet

In Rajasthan:

- **Context**: Semi-arid (400–600 mm rainfall), sandy soils, low SOM (<0.5%).
- **Crops**: Pearl millet (*HHB 67*), groundnut.
- **Constraints**:
  - Low rainfall (30–50% variability).
  - Drought stress (1 in 3 years).
  - Low fertility (N: 150 kg/ha, P: 5 mg/kg).
- **Management**:
  - Moisture conservation: Mulching with crop residues (5 t/ha).
  - Varieties: *HHB 67* pearl millet (short-duration, drought-tolerant).
  - INM: FYM (10 t/ha), *Azotobacter* (2 kg/ha).
- **Impact**: Increases pearl millet yield by 10–20% (1–2 t/ha), improves WUE by 20%. This case study illustrates dryland farming challenges and solutions, a key exam concept.

Conclusion

This part has explored the concept of dryland farming, its comparison with rainfed farming, history, development, significance, and constraints, vital for the ASRB NET JRF exam. Dryland farming, reliant on low rainfall (300–800 mm), supports 60% of India's farmland, facing challenges like drought and low fertility, mitigated through conservation and tolerant varieties.

Climatic Classification and Delineation of Dryland Tracts, Characterization of Agro-Climatic Environments

Introduction

Climatic classification and delineation of dryland tracts are foundational for effective dryland agronomy in India, where 60% of farmland relies on erratic rainfall, impacting yields by 20–50% (ICAR, 2023). This part explores climatic zones (arid, semi-arid, sub-humid), delineation of dryland regions, and agro-climatic environment characteristics.

Climatic Classification of Dryland Regions

Definition and Importance

Climatic classification categorizes regions based on rainfall, temperature, and evapotranspiration, guiding crop selection, moisture conservation, and drought management in dryland agriculture. In India, classification identifies arid, semi-arid, and sub-humid zones, critical for planning resilient farming systems.

Importance:

- **Crop Suitability**: Matches crops to climate (e.g., millets in arid zones).
- **Resource Allocation**: Directs conservation efforts (e.g., farm ponds in semi-arid areas).
- **Policy Planning**: Informs schemes like PMKSY for dryland development.
- **Example**: Arid Rajasthan grows pearl millet, while sub-humid Maharashtra supports soybean.

Classification Systems

1. **Thornthwaite's Classification (1948)**:
   - **Basis**: Moisture index (MI) = (P - PET) / PET, where P = precipitation, PET = potential evapotranspiration.
   - **Zones**:
     - **Arid**: MI < -0.66, rainfall <400 mm (e.g., Thar Desert).
     - **Semi-Arid**: MI -0.66 to -0.33, rainfall 400–800 mm (e.g., Deccan Plateau).
     - **Sub-Humid**: MI -0.33 to 0, rainfall 800–1200 mm (e.g., Vidarbha).
   - **Use**: Identifies dryland zones for crop planning.
   - **Example**: Semi-arid Karnataka (MI -0.5) grows sorghum.
2. **Köppen's Classification**:
   - **Basis**: Temperature, precipitation patterns.
   - **Zones**:
     - **BWh/BSh**: Arid hot/cold (e.g., Rajasthan).
     - **Cwb/Csb**: Semi-arid with dry winters (e.g., parts of Maharashtra).
   - **Use**: Maps dryland tracts for research.
   - **Example**: BSh zone in Gujarat supports groundnut.

3. **ICAR Classification**:
   - **Basis**: Rainfall, length of growing season (LGS).
   - **Zones**:
     - **Arid**: <400 mm, LGS <90 days.
     - **Semi-Arid**: 400–800 mm, LGS 90–150 days.
     - **Sub-Humid**: 800–1200 mm, LGS 150–210 days.
   - **Use**: Guides AICRPDA research, policy (e.g., NRAA).
   - **Example**: Arid Rajasthan (LGS 60–90 days) grows pearl millet.

Climatic Zones in India

- **Arid**:
  - Rainfall: <400 mm, PET >1500 mm.
  - Regions: Western Rajasthan, parts of Gujarat, Haryana.
  - Crops: Pearl millet, guar, moth bean.
  - **Example**: Thar Desert (200–300 mm) grows *HHB 67* pearl millet.
- **Semi-Arid**:
  - Rainfall: 400–800 mm, PET 1000–1500 mm.
  - Regions: Deccan Plateau, parts of Karnataka, Andhra Pradesh, Maharashtra.
  - Crops: Sorghum, groundnut, pigeonpea.
  - **Example**: Anantapur (500 mm) grows groundnut.
- **Sub-Humid**:
  - Rainfall: 800–1200 mm, PET 800–1000 mm.
  - Regions: Vidarbha, eastern Rajasthan, parts of Madhya Pradesh.
  - Crops: Soybean, cotton, maize.
  - **Example**: Amravati (900 mm) grows soybean.

Classification Data

Zone	Rainfall (mm)	MI (Thornthwaite)	LGS (days)	Crops	Regions
Arid	<400	<-0.66	<90	Pearl millet, guar	Rajasthan, Gujarat
Semi-Arid	400–800	-0.66 to -0.33	90–150	Sorghum, groundnut	Karnataka, AP
Sub-Humid	800–1200	-0.33 to 0	150–210	Soybean, cotton	Vidarbha, MP

PYQ Analysis

1. What defines an arid zone?
   (A) >800 mm rainfall,
   (B) <400 mm rainfall,
   (C) 1200 mm rainfall,
   (D) High irrigation.

Answer: (B) <400 mm rainfall.
Explanation: Arid zones have <400 mm rainfall, high PET.

2. Which crop is grown in semi-arid zones?
   (A) Rice, (B) Sorghum,
   (C) Sugarcane, (D) Wheat.

Answer: (B) Sorghum.
Explanation: Sorghum is suited for 400–800 mm rainfall.

3. What is the moisture index for sub-humid zones?
   (A) <-0.66, (B) -0.33 to 0,
   (C) >0, (D) -1.

Answer: (B) -0.33 to 0.
Explanation: Sub-humid zones have MI -0.33 to 0.

- **Trend**: PYQs focus on climatic zones, rainfall thresholds, and crop suitability, with recent emphasis on moisture indices and LGS.

Delineation of Dryland Tracts in India

Definition and Importance

Delineation of dryland tracts identifies geographical areas with low rainfall and high moisture stress, guiding agricultural planning, research, and policy. In India, dryland tracts cover 80 Mha (60% of farmland), primarily in arid and semi-arid zones (ICAR, 2023).

Importance:

- **Crop Planning**: Identifies suitable crops (e.g., millets in Rajasthan).
- **Resource Management**: Directs watershed programs to dryland areas.

- **Policy Support**: Informs NRAA, PMKSY for dryland development.
- **Example**: Delineation in Rajasthan prioritizes farm ponds for pearl millet.

Methodology for Delineation

- **Rainfall-Based**:
  - Arid: <400 mm; Semi-Arid: 400–800 mm; Sub-Humid: 800–1200 mm.
  - Data: IMD rainfall records, CRIDA agro-ecological zones.
- **Moisture Index (MI)**:
  - Calculated as MI = (P - PET) / PET.
  - Thresholds: Arid (< -0.66), Semi-Arid (-0.66 to -0.33).
- **Length of Growing Season (LGS)**:
  - Determined by rainfall duration, soil moisture (LGS <90 days for arid zones).
  - Data: Soil moisture models, ICAR agro-climatic zones.
- **Geospatial Tools**:
  - GIS, remote sensing map dryland tracts (e.g., NDVI for moisture stress).
  - Example: GIS maps delineate semi-arid tracts in Andhra Pradesh.

Major Dryland Tracts

1. **Western Arid Zone**:
   - **Regions**: Western Rajasthan, parts of Gujarat, Haryana (10 Mha).
   - **Rainfall**: 200–400 mm, LGS 60–90 days.
   - **Crops**: Pearl millet, guar, moth bean.
   - **Example**: Jaisalmer (250 mm) grows *HHB 67* pearl millet.
2. **Deccan Plateau Semi-Arid Zone**:
   - **Regions**: Karnataka, Andhra Pradesh, Telangana, Maharashtra (40 Mha).
   - **Rainfall**: 400–800 mm, LGS 90–150 days.
   - **Crops**: Sorghum, groundnut, pigeonpea.
   - **Example**: Anantapur (500 mm) grows groundnut.
3. **Central Semi-Arid Zone**:
   - **Regions**: Madhya Pradesh, eastern Rajasthan, parts of Uttar Pradesh (20 Mha).
   - **Rainfall**: 600–800 mm, LGS 120–150 days.
   - **Crops**: Soybean, sorghum, pulses.
   - **Example**: Bundelkhand (700 mm) grows urdbean.
4. **Sub-Humid Dryland Zone**:
   - **Regions**: Vidarbha, parts of Odisha, Chhattisgarh (10 Mha).
   - **Rainfall**: 800–1200 mm, LGS 150–210 days.
   - **Crops**: Soybean, cotton, maize.
   - **Example**: Amravati (900 mm) grows soybean.

Delineation Data

Tract	Regions	Rainfall (mm)	LGS (days)	Crops
Western Arid	Rajasthan, Gujarat	200–400	60–90	Pearl millet, guar
Deccan Semi-Arid	Karnataka, AP, Maharashtra	400–800	90–150	Sorghum, groundnut
Central Semi-Arid	MP, Rajasthan, UP	600–800	120–150	Soybean, pulses
Sub-Humid	Vidarbha, Odisha	800–1200	150–210	Soybean, cotton

Applications

- **Crop Selection**: Pearl millet for arid zones, soybean for sub-humid zones.
- **Conservation Planning**: Farm ponds in arid Rajasthan, mulching in semi-arid Karnataka.
- **Research**: CRIDA targets Deccan for sorghum improvement.
- **Example**: Delineation in Anantapur guides groundnut cultivation with check dams.

PYQ Analysis

1. Which region is an arid dryland tract?

   (A) Vidarbha, (B) Rajasthan,

   (C) Punjab, (D) Kerala.

Answer: (B) Rajasthan.

Explanation: Western Rajasthan has <400 mm rainfall.

2. What delineates semi-arid tracts?
   (A) >1200 mm, (B) 400–800 mm,
   (C) <200 mm, (D) Irrigation.

Answer: (B) 400–800 mm.

Explanation: Semi-arid zones have 400–800 mm rainfall.

3. Which crop is grown in sub-humid drylands?
   (A) Pearl millet, (B) Soybean,
   (C) Sugarcane, (D) Rice.

Answer: (B) Soybean.

Explanation: Soybean suits 800–1200 mm rainfall zones.

- **Trend**: PYQs focus on tract delineation, rainfall, and crops, with recent emphasis on geospatial tools.

Characterization of Agro-Climatic Environments

Definition and Importance

Characterization of agro-climatic environments describes the climatic, soil, and biotic factors influencing dryland agriculture, guiding crop selection, moisture conservation, and management. In India, diverse environments (arid to sub-humi(D) shape dryland practices (ICAR, 2023).

Importance:

- **Crop Adaptation**: Matches crops to environment (e.g., sorghum in semi-arid Deccan).
- **Management Planning**: Informs conservation (e.g., mulching in low-rainfall zones).
- **Research**: Directs CRIDA, AICRPDA to region-specific solutions.
- **Example**: Low SOM in Rajasthan's arid soils prompts FYM use for pearl millet.

Key Characteristics

- **Rainfall**:
  - **Range**: 200–1200 mm, with 30–50% variability.
  - **Distribution**: Monsoon-driven (June–September), 70–80% annual rainfall.
  - **Impact**: Erratic rainfall reduces yields by 20–50%.
  - **Example**: Rajasthan's 300 mm rainfall limits LGS to 60–90 days.
- **Temperature**:
  - **Range**: 20–40°C (summer), 10–25°C (winter).
  - **Impact**: High temperatures increase PET (1500–2000 mm), causing stress.
  - **Example**: 35–40°C in Gujarat's drylands affects groundnut flowering.
- **Soil Types**:
  - **Types**:
    - **Arid**: Sandy, low SOM (<0.5%), low CEC (5–10 cmol/kg).
    - **Semi-Arid**: Red, black, loamy soils, SOM 0.5–1%.
    - **Sub-Humid**: Alluvial, clayey soils, SOM 1–2%.
  - **Impact**: Sandy soils limit nutrient retention; black soils retain moisture.
  - **Example**: Black soils in Maharashtra support pigeonpea.
- **Length of Growing Season (LGS)**:
  - **Range**: 60–210 days (arid: <90, semi-arid: 90–150, sub-humid: 150–210).
  - **Impact**: Short LGS restricts crop choice (e.g., millets in arid zones).
  - **Example**: LGS of 120 days in Karnataka suits sorghum.
- **Biotic Factors**:
  - **Crops**: Millets, pulses, oilseeds dominate.
  - **Pests/Weeds**: Shoot borer in sorghum, *Striga* in millets.
  - **Impact**: Pests reduce yields by 10–20%.
  - **Example**: *Striga* in Rajasthan's pearl millet fields causes 15% loss.

Agro-Climatic Data

Zone	Rainfall (mm)	Temperature (°C)	Soil Type	LGS (days)	Crops
Arid	200–400	25–40	Sandy, low SOM	60–90	Pearl millet, guar
Semi-Arid	400–800	20–35	Red, black	90–150	Sorghum, groundnut
Sub-Humid	800–1200	20–30	Alluvial, clayey	150–210	Soybean, cotton

Applications

- **Crop Selection**: Pearl millet for sandy, arid soils; soybean for clayey, sub-humid soils.
- **Conservation**: Mulching in sandy soils, farm ponds in black soils.
- **Variety Development**: Short-duration sorghum for semi-arid Deccan.
- **Example**: Black soils in Maharashtra's semi-arid zone support pigeonpea intercropping.

PYQ Analysis

1. What characterizes arid soils?
   (A) High SOM, (B) Low SOM,
   (C) Clayey, (D) High fertility.

Answer: (B) Low SOM.

Explanation: Arid soils have <0.5% SOM, low nutrient retention.

2. What is the LGS in semi-arid zones?
   (A) <90 days, (B) 90–150 days,
   (C) >210 days, (D) 300 days.

Answer: (B) 90–150 days.

Explanation: Semi-arid zones have LGS of 90–150 days.

3. Which soil type supports pigeonpea?
   (A) Sandy, (B) Black,
   (C) Saline, (D) Peaty.

Answer: (B) Black.

Explanation: Black soils in semi-arid zones retain moisture for pigeonpea.

4. What affects dryland yields?
   (A) High rainfall,
   (B) Erratic rainfall,
   (C) Irrigation,
   (D) Low temperature.

Answer: (B) Erratic rainfall.

Explanation: Rainfall variability reduces yields by 20–50%.

- **Trend**: PYQs focus on environmental characteristics, soil types, and LGS, with recent emphasis on crop adaptation and conservation.

Case Study: Agro-Climatic Environment in Karnataka's Semi-Arid Drylands

In Karnataka:

- **Environment**:
  - **Rainfall**: 500–700 mm, 70% in June–September, 40% variability.
  - **Temperature**: 25–35°C, PET 1200–1500 mm.
  - **Soil**: Red, loamy, SOM 0.5–1%, low P (5–10 mg/kg).
  - **LGS**: 90–120 days.
  - **Biotic**: Sorghum, groundnut; pests like shoot borer.
- **Management**:
  - Crops: *CSV 15* sorghum, *JL 24* groundnut.
  - Conservation: Mulching (5 t/ha crop residues), farm ponds.
  - INM: FYM (10 t/ha), DAP (40 kg/ha P_2O_5).
- **Impact**: Increases sorghum yield by 10–20% (1–2 t/ha), improves WUE by 20%. This case study illustrates agro-climatic characterization and management, a key exam concept.

Conclusion

This part has explored climatic classification, delineation of dryland tracts, and characterization of agro-climatic environments, vital for the ASRB NET JRF exam. Arid (<400 mm), semi-arid (400–800 mm), and sub-humid (800–1200 mm) zones guide crop selection and conservation, with 80 Mha of dryland tracts supporting millets, pulses, and oilseeds. Environmental factors like erratic rainfall and low SOM shape management strategies.

Rainfall Analysis and Length of Growing Season

Introduction

Rainfall analysis and the length of growing season (LGS) are critical for planning dryland agriculture in India, where 60% of farmland depends on erratic rainfall, causing 20–50% yield variability (ICAR, 2023).

Rainfall Analysis in Dryland Agriculture

Definition and Importance

Rainfall analysis involves studying the amount, distribution, variability, and timing of precipitation in dryland regions to guide crop selection, sowing schedules, and moisture conservation. In India, drylands receive 300–1200 mm rainfall annually, with 30–60% variability, impacting yields and livelihoods (ICAR, 2023).

Importance:

- **Crop Planning**: Determines suitable crops (e.g., millets for <400 mm).
- **Drought Preparedness**: Identifies variability for contingency plans.
- **Water Management**: Informs conservation (e.g., farm ponds).
- **Example**: Rainfall analysis in Rajasthan's arid zone (300 mm) supports pearl millet cultivation.

Components of Rainfall Analysis

1. **Amount of Rainfall**:
    - **Range**:
        - Arid: <400 mm (e.g., Rajasthan: 200–300 mm).
        - Semi-arid: 400–800 mm (e.g., Karnataka: 500–700 mm).
        - Sub-humid: 800–1200 mm (e.g., Vidarbha: 900 mm).
    - **Impact**: Low rainfall limits crop choice, reduces yields by 20–50%.
    - **Measurement**: Rain gauges, IMD data (mm/year, monthly averages).
    - **Example**: Anantapur's 500 mm rainfall supports groundnut in semi-arid zones.
2. **Distribution**:
    - **Pattern**: 70–80% rainfall in June–September (Southwest Monsoon).
    - **Impact**: Uneven distribution (e.g., 50% in July) causes early-season drought or late-season stress.
    - **Analysis**: Monthly rainfall charts, cumulative rainfall curves.
    - **Example**: Karnataka's 70% rainfall in July–August suits short-duration sorghum.
3. **Variability**:
    - **Range**: 30–60% coefficient of variation (CV) in drylands.
    - **Impact**: High CV (>40%) increases drought risk, reducing yields by 30–50%.
    - **Measurement**: CV = (Standard Deviation ÷ Mean Rainfall) × 100.
    - **Example**: Rajasthan's rainfall CV of 50% causes frequent pearl millet failures.
4. **Monsoon Timing**:
    - **Onset**: Normal onset June 15–20; delayed onset (July) shortens LGS.
    - **Withdrawal**: September–October; early withdrawal causes terminal drought.
    - **Impact**: Delayed onset reduces LGS by 10–20 days, affecting sowing.
    - **Example**: Delayed monsoon in Maharashtra (July 10) shifts soybean sowing.

Rainfall Characteristics by Zone

Zone	Rainfall (mm)	Distribution (% Monsoon)	Variability (CV %)	Monsoon Onset	Crops
Arid	200–400	80–90% (Jun–Sep)	40–60%	Jun 20–30	Pearl millet, guar
Semi-Arid	400–800	70–80% (Jun–Sep)	30–50%	Jun 15–25	Sorghum, groundnut
Sub-Humid	800–1200	60–70% (Jun–Sep)	20–30%	Jun 10–20	Soybean, cotton

Methods of Rainfall Analysis

- **Historical Data Analysis**:
  - **Source**: IMD, CRIDA (30–50 years of rainfall data).
  - **Tools**: Statistical software (e.g., R, SPSS) for mean, CV, trends.
  - **Use**: Predicts sowing windows, drought probability.
  - **Example**: 50-year data in Rajasthan shows 40% drought probability.
- **Probability Analysis**:
  - **Method**: Markov chain, Weibull distribution for rainfall probability.
  - **Use**: Estimates rainfall at 75% probability (e.g., 400 mm in Karnataka).
  - **Example**: 75% probability rainfall in Anantapur guides groundnut sowing.
- **Cumulative Rainfall Curves**:
  - **Method**: Plots cumulative rainfall vs. time (weekly/monthly).
  - **Use**: Identifies moisture availability for crop stages.
  - **Example**: Curve for Maharashtra shows 70% rainfall by mid-August, suiting pigeonpea.
- **Geospatial Analysis**:
  - **Tools**: GIS, remote sensing (e.g., TRMM, IMERG data).
  - **Use**: Maps rainfall patterns, variability across fields.
  - **Example**: GIS maps in Gujarat identify 300 mm zones for pearl millet.

Applications

- **Crop Selection**: Millets for <400 mm, soybean for 800–1200 mm.
- **Sowing Schedules**: Early sowing in June for 120-day LGS in semi-arid zones.
- **Conservation Planning**: Farm ponds in high-variability areas (CV >40%).
- **Example**: Rainfall analysis in Karnataka schedules sorghum sowing for mid-June.

PYQ Analysis

1. What is the rainfall range for semi-arid zones?
   (A) <400 mm, (B) 400–800 mm,
   (C) >1200 mm, (D) 1500 mm.

Answer: (B) 400–800 mm.

Explanation: Semi-arid zones receive 400–800 mm rainfall.

2. What causes yield variability in drylands?
   (A) High irrigation,
   (B) Rainfall variability,
   (C) High fertility,
   (D) Low temperature.

Answer: (B) Rainfall variability.

Explanation: 30–60% CV reduces yields by 20–50%.

3. When is the monsoon onset in arid zones?
   (A) Jun 1–10, (B) Jun 20–30,
   (C) Jul 10–20, (D) Aug 1–10.

Answer: (B) Jun 20–30.

Explanation: Arid zones have late monsoon onset (Jun 20–30).

4. Which crop suits high rainfall variability?
   (A) Rice, (B) Pearl millet,
   (C) Sugarcane, (D) Wheat.

Answer: (B) Pearl millet.

Explanation: Pearl millet tolerates 40–60% CV.

5. What tool analyzes rainfall variability?
   (A) pH meter, (B) GIS,
   (C) Thermometer, (D) Rain gauge.

Answer: (B) GIS.

Explanation: GIS maps rainfall patterns and variability.

- **Trend**: PYQs focus on rainfall ranges, variability, and analysis methods, with recent emphasis on geospatial tools and monsoon timing.

Length of Growing Season (LGS)

Definition and Importance

The length of growing season (LGS) is the period during which soil moisture and temperature support crop growth, typically from monsoon onset to cessation of effective rainfall. In dryland India, LGS ranges from 60–210 days, determining crop suitability and yield potential (ICAR, 2023).

Importance:

- **Crop Selection**: Matches crop duration to LGS (e.g., 90-day millets for arid zones).
- **Sowing Timing**: Aligns sowing with moisture availability.
- **Yield Stability**: Longer LGS supports higher yields (e.g., soybean in sub-humid zones).
- **Example**: 120-day LGS in Karnataka suits short-duration sorghum.

Calculation of LGS

1. **FAO Method**:
    - **Definition**: Period when rainfall exceeds 0.5 × PET and soil moisture supports growth.
    - **Formula**: LGS = Days when P > 0.5 × PET, plus stored moisture period.
    - **Example**: Karnataka (600 mm rainfall, PET 1200 mm) has LGS of 90–120 days.
2. **ICAR Method**:
    - **Definition**: Period from monsoon onset (P >20 mm/week) to cessation (P <10 mm/week).
    - **Example**: Rajasthan's LGS of 60–90 days starts mid-July, ends mid-September.
3. **Soil Moisture Balance**:
    - **Method**: Tracks soil water availability using models (e.g., CROPWAT).
    - **Example**: Maharashtra's black soils extend LGS by 10–20 days due to moisture retention.

LGS by Dryland Zone

- **Arid** (<400 mm):
    - LGS: 60–90 days.
    - Crops: Pearl millet (*HHB 67*, 70 days), guar (80 days).
    - **Example**: Jaisalmer's 60-day LGS suits pearl millet.
- **Semi-Arid** (400–800 mm):
    - LGS: 90–150 days.
    - Crops: Sorghum (*CSV 15*, 100 days), groundnut (*JL 24*, 120 days).
    - **Example**: Anantapur's 120-day LGS supports groundnut.
- **Sub-Humid** (800–1200 mm):
    - LGS: 150–210 days.
    - Crops: Soybean (*JS 335*, 100 days), cotton (150 days).
    - **Example**: Vidarbha's 180-day LGS suits soybean.

LGS Data

Zone	Rainfall (mm)	LGS (days)	Crops	Sowing Period
Arid	200–400	60–90	Pearl millet, guar	Mid-Jul
Semi-Arid	400–800	90–150	Sorghum, groundnut	Mid-Jun to Jul
Sub-Humid	800–1200	150–210	Soybean, cotton	Early Jun

Factors Affecting LGS

- **Rainfall Amount and Distribution**:
    - Low rainfall (<400 mm) shortens LGS; even distribution extends it.
    - **Example**: Uneven rainfall in Rajasthan limits LGS to 60 days.
- **Soil Type**:
    - Black soils retain moisture, extending LGS by 10–20 days.
    - Sandy soils shorten LGS due to low water-holding capacity.
    - **Example**: Maharashtra's black soils support 150-day LGS for pigeonpea.
- **Temperature**:
    - High temperatures (35–40°(C) increase PET, reducing LGS.
    - **Example**: Gujarat's 40°C summer shortens LGS for groundnut.
- **Monsoon Timing**:
    - Delayed onset (July) reduces LGS by 10–20 days.
    - Early withdrawal (September) causes terminal drought.
    - **Example**: Delayed monsoon in Karnataka shortens sorghum LGS.
- **Conservation Practices**:
    - Mulching, farm ponds extend LGS by 10–15 days.
    - **Example**: Farm ponds in Rajasthan extend LGS for pearl millet.

Applications

- **Crop Selection**: Short-duration crops (e.g., 70-day pearl millet) for arid zones.
- **Sowing Schedules**: Align sowing with monsoon onset (e.g., mid-June for sorghum).
- **Contingency Planning**: Shift to shorter-duration varieties if monsoon delays.
- **Example**: 120-day LGS in Anantapur schedules groundnut sowing for mid-June.

PYQ Analysis

1. What is the LGS in arid zones?
   (A) <90 days, (B) 150–210 days,
   (C) >300 days, (D) 90–150 days.

Answer: (A) <90 days.

Explanation: Arid zones have LGS of 60–90 days due to low rainfall.

2. Which crop suits a 120-day LGS?
   (A) Rice, (B) Sorghum,
   (C) Sugarcane, (D) Wheat.

Answer: (B) Sorghum.

Explanation: Sorghum (100–120 days) fits semi-arid LGS.

3. What shortens LGS in drylands?
   (A) High SOM,
   (B) Delayed monsoon,
   (C) Irrigation,
   (D) Low PET.

Answer: (B) Delayed monsoon.

Explanation: Delayed onset reduces LGS by 10–20 days.

4. How is LGS calculated?
   (A) Rainfall > PET, (B) P > 0.5 × PET,
   (C) Temperature, (D) Soil pH.

Answer: (B) P > 0.5 × PET.

Explanation: LGS is when rainfall exceeds 0.5 × PET.

5. Which soil extends LGS?
   (A) Sandy, (B) Black,
   (C) Saline, (D) Peaty.

Answer: (B) Black.

Explanation: Black soils retain moisture, extending LGS.

- **Trend**: PYQs focus on LGS ranges, calculations, and influencing factors, with recent emphasis on crop suitability and conservation practices.

Case Study: Rainfall Analysis and LGS in Maharashtra's Semi-Arid Drylands

In Maharashtra (Anantapur district):

- **Rainfall**:
  - **Amount**: 600 mm (CV: 40%).
  - **Distribution**: 70% in July–August, onset mid-June.
  - **Analysis**: IMD data shows 75% probability of 500 mm, guiding sowing.
- **LGS**:
  - **Duration**: 120–150 days (mid-Jun to mid-Oct).
  - **Calculation**: P > 0.5 × PET (PET: 1200 mm), black soils extend LGS.
- **Management**:
  - **Crops**: *CSV 15* sorghum (100 days), *JS 335* soybean (100 days).
  - **Sowing**: Mid-June, adjusted for delayed onset (July).
  - **Conservation**: Mulching (5 t/ha), farm ponds (10 m^3/ha).
- **Impact**: Increases sorghum yield by 10–20% (1–2 t/ha), stabilizes soybean production. This case study illustrates rainfall analysis and LGS applications, a key exam concept.

Conclusion

This part has explored rainfall analysis and length of growing season (LGS), vital for the ASRB NET JRF exam. Rainfall (300–1200 mm) with 30–60% variability shapes dryland agriculture, analyzed through historical data, probability models, and GIS. LGS (60–210 days) determines crop suitability, influenced by rainfall, soil, and conservation practices.

Types of Drought, Drought Syndrome, And Effects on Plant Growth

Introduction

Drought is a major constraint in Indian dryland agriculture, affecting 60% of farmland and causing 20–50% yield losses (ICAR, 2023). This part explores types of drought, drought syndrome, and their effects on plant growth.

Types of Drought

Definition and Importance

Drought is a prolonged period of below-normal precipitation, leading to water scarcity that impacts agriculture, ecosystems, and water resources. In dryland India, droughts occur in 1 out of 3 years, reducing crop yields and threatening food security. Classifying drought types aids in planning mitigation strategies.

Importance:

- **Crop Management**: Guides crop selection (e.g., drought-tolerant millets).
- **Water Conservation**: Informs practices like farm ponds.
- **Policy Planning**: Supports drought relief under NRAA, PMKSY.
- **Example**: Agricultural drought in Rajasthan's pearl millet fields prompts contingency cropping.

Types of Drought

- **Meteorological Drought**:
    - **Definition**: Deficiency in rainfall compared to long-term average (e.g., <75% of normal).
    - **Criteria**:
        - Mild: 75–90% of normal rainfall.
        - Moderate: 50–75% of normal.
        - Severe: <50% of normal.
    - **Impact**: Triggers other droughts, reduces soil moisture.
    - **Regions**: Arid Rajasthan (200–300 mm), semi-arid Karnataka (500 mm).
    - **Example**: 2015 drought in Maharashtra (60% of normal rainfall) affected sorghum.
- **Agricultural Drought**:
    - **Definition**: Insufficient soil moisture to meet crop water needs during critical growth stages.
    - **Criteria**: Soil moisture <50% of field capacity, rainfall deficit during sowing/flowering.
    - **Impact**: Reduces yields by 20–50% (e.g., groundnut in semi-arid zones).
    - **Regions**: Deccan Plateau, central India.
    - **Example**: Agricultural drought in Anantapur (2018) caused 30% groundnut yield loss.
- **Hydrological Drought**:
    - **Definition**: Depletion of surface and groundwater resources (e.g., low reservoir levels).
    - **Criteria**: Streamflow <25% of normal, groundwater table drop >2 m.
    - **Impact**: Limits irrigation, affects rainfed crops in sub-humid zones.
    - **Regions**: Vidarbha, parts of Madhya Pradesh.
    - **Example**: Hydrological drought in Marathwada (2016) reduced soybean irrigation.
- **Socio-Economic Drought**:
    - **Definition**: Water scarcity impacting livelihoods, food security, and economy.
    - **Criteria**: Reduced crop production, increased food prices, migration.
    - **Impact**: Affects 68% of dryland farmers, increases rural distress.
    - **Example**: 2019 drought in Rajasthan led to 20% migration from dryland villages.

Drought Types Data

Type	Criteria	Impact	Regions Affected
Meteorological	<75% normal rainfall	Triggers other droughts	Rajasthan, Karnataka
Agricultural	Soil moisture <50% field capacity	20–50% yield loss	Deccan, central India
Hydrological	Streamflow <25%, low groundwater	Limited irrigation	Vidarbha, MP
Socio-Economic	Reduced production, migration	Rural distress	Rajasthan, Maharashtra

Applications

- **Crop Selection**: Drought-tolerant varieties (e.g., *HHB 67* pearl millet) for meteorological drought.
- **Moisture Conservation**: Mulching, farm ponds for agricultural drought.
- **Water Management**: Check dams for hydrological drought.
- **Relief Measures**: PMKSY subsidies for socio-economic drought.
- **Example**: Mulching in Karnataka's sorghum fields mitigates agricultural drought.

PYQ Analysis

1. What defines meteorological drought?
   (A) Low soil moisture,
   (B) <75% normal rainfall,
   (C) Low groundwater,
   (D) Migration.

Answer: (B) <75% normal rainfall.

Explanation: Meteorological drought is a rainfall deficit.

2. Which drought affects crop yields?
   (A) Hydrological, (B) Agricultural,
   (C) Socio-Economic, (D) All.

Answer: (B) Agricultural.

Explanation: Agricultural drought reduces soil moisture, impacting yields.

3. What is a criterion for hydrological drought?
   (A) High rainfall,
   (B) Low streamflow,
   (C) High SOM,
   (D) Early monsoon.

Answer: (B) Low streamflow.

Explanation: Hydrological drought involves reduced water resources.

4. Which region faces severe meteorological drought?
   (A) Punjab, (B) Rajasthan,
   (C) Kerala, (D) Assam.

Answer: (B) Rajasthan.

Explanation: Rajasthan's <400 mm rainfall triggers severe droughts.

5. What is an impact of socio-economic drought?
   (A) Yield increase, (B) Migration,
   (C) High fertility, (D) Irrigation.

Answer: (B) Migration.

Explanation: Socio-economic drought causes rural distress, migration.

- **Trend**: PYQs focus on drought types, criteria, and impacts, with recent emphasis on agricultural and socio-economic effects.

Drought Syndrome

Definition and Importance

Drought syndrome refers to the cumulative physiological, biochemical, and morphological responses of plants to water stress, leading to reduced growth, yield, and survival. In dryland India, drought syndrome causes 20–50% yield losses, necessitating resistant varieties and management (ICAR, 2023).

Importance:

- **Crop Resilience**: Informs breeding for drought tolerance (e.g., sorghum).
- **Management Strategies**: Guides conservation, contingency planning.
- **Yield Protection**: Mitigates losses through timely interventions.
- **Example**: Drought syndrome in Rajasthan's pearl millet reduces grain yield by 30%.

Components of Drought Syndrome

1. **Physiological Responses**:
   - **Stomatal Closure**: Reduces transpiration, limits CO_2 uptake.
   - **Reduced Photosynthesis**: Lowers carbohydrate production by 20–40%.
   - **Water Potential Decline**: Leaf water potential drops (e.g., -1.5 to -2.5 MPa).
   - **Example**: Stomatal closure in groundnut under drought reduces photosynthesis.
2. **Biochemical Responses**:
   - **Osmotic Adjustment**: Accumulation of solutes (e.g., proline, glycine betaine) maintains turgor.
   - **Antioxidant Production**: Enzymes (e.g., SOD, CAT) combat oxidative stress.
   - **Protein Denaturation**: Drought disrupts enzyme activity (e.g., Rubisco).
   - **Example**: Proline accumulation in sorghum enhances drought tolerance.
3. **Morphological Responses**:
   - **Reduced Leaf Area**: Smaller leaves (20–30% reduction) minimize water loss.
   - **Root Growth**: Deeper roots (e.g., 1–2 m) access subsoil moisture.
   - **Wilting**: Temporary or permanent wilting under severe stress.
   - **Example**: Deep roots in pigeonpea access moisture during drought.
4. **Yield Impacts**:
   - **Flowering Failure**: Drought at flowering reduces grain set by 30–50%.
   - **Grain Filling**: Smaller grains (10–20% weight loss) lower yield.
   - **Example**: Drought at sorghum flowering reduces yield by 40%.

Drought Syndrome Data

Component	Response	Impact	Example Crop
Physiological	Stomatal closure, low photosynthesis	20–40% carbohydrate loss	Groundnut
Biochemical	Proline accumulation, antioxidants	Maintains turgor, reduces stress	Sorghum
Morphological	Reduced leaf area, deep roots	Minimizes water loss	Pigeonpea
Yield Impacts	Flowering failure, small grains	30–50% yield loss	Pearl millet

Applications

- **Breeding**: Develop varieties with osmotic adjustment (e.g., *CSV 15* sorghum).
- **Management**: Mulching, foliar sprays reduce stress effects.
- **Monitoring**: Use NDVI to assess drought stress in fields.
- **Example**: Foliar sprays in Maharashtra's soybean mitigate drought syndrome.

PYQ Analysis

1. What is a physiological response to drought?
   (A) Leaf expansion,
   (B) Stomatal closure,
   (C) High photosynthesis,
   (D) Shallow roots.

Answer: (B) Stomatal closure.

Explanation: Stomatal closure reduces water loss during drought.

2. Which biochemical helps drought tolerance?
   (A) Proline, (B) Glucose,
   (C) Starch, (D) Lipid.

Answer: (A) Proline.

Explanation: Proline maintains turgor under drought stress.

3. What reduces yield in drought?
   (A) Large leaves,
   (B) Flowering failure,
   (C) High SOM,
   (D) Irrigation.

Answer: (B) Flowering failure.

Explanation: Drought at flowering reduces grain set by 30–50%.

4. What morphological trait aids drought?
   (A) Shallow roots, (B) Deep roots,
   (C) Large leaves, (D) Thin stems.

Answer: (B) Deep roots.

Explanation: Deep roots access subsoil moisture.

5. What is drought syndrome?
   (A) Yield increase,
   (B) Plant stress responses,
   (C) High fertility,
   (D) Irrigation.

Answer: (B) Plant stress responses.

Explanation: Drought syndrome includes physiological, biochemical responses.

- **Trend**: PYQs focus on physiological, biochemical, and yield impacts, with recent emphasis on drought tolerance mechanisms.

Effects on Plant Growth

Definition and Importance

Drought effects on plant growth encompass physiological, biochemical, and morphological changes that impair development, reducing biomass, yield, and survival. In dryland India, these effects cause 20–50% yield losses, necessitating resistant varieties and management (ICAR, 2023).

Importance:

- **Yield Protection**: Mitigates losses through timely interventions.
- **Crop Improvement**: Guides breeding for drought tolerance.
- **Management**: Informs conservation, irrigation strategies.
- **Example**: Drought stress in Rajasthan's pearl millet reduces grain yield by 30–50%.

Physiological Effects

- **Reduced Photosynthesis**:
  - **Mechanism**: Stomatal closure limits CO_2, reducing Rubisco activity.
  - **Impact**: 20–40% lower carbohydrate production, stunted growth.
  - **Example**: Photosynthesis in groundnut drops by 30% under drought.
- **Water Potential Decline**:
  - **Mechanism**: Low soil moisture reduces leaf water potential (-1.5 to -2.5 MPa).
  - **Impact**: Inhibits cell expansion, reduces turgor.
  - **Example**: Sorghum leaves wilt at -2 MPa, limiting growth.
- **Hormonal Changes**:
  - **Mechanism**: Increased abscisic acid (ABA) triggers stomatal closure.
  - **Impact**: Slows growth, prioritizes survival.
  - **Example**: ABA in pigeonpea reduces shoot growth under drought.

Biochemical Effects

1. **Osmotic Adjustment**:
   - **Mechanism**: Accumulation of proline, glycine betaine maintains turgor.
   - **Impact**: Enhances cell hydration, improves survival by 10–20%.
   - **Example**: Proline in sorghum increases drought tolerance.
2. **Oxidative Stress**:
   - **Mechanism**: Reactive oxygen species (ROS) damage membranes, proteins.
   - **Impact**: 20–30% reduction in enzyme activity (e.g., SOD, CAT).
   - **Example**: ROS in pearl millet causes lipid peroxidation.
3. **Metabolic Disruption**:
   - **Mechanism**: Reduced enzyme activity (e.g., nitrate reductase) limits N assimilation.
   - **Impact**: Lowers protein synthesis, stunts growth.
   - **Example**: Reduced N uptake in groundnut under drought.

Morphological Effects

- **Reduced Leaf Area**:
  - **Mechanism**: Smaller leaves (20–30% reduction) minimize transpiration.

Toppersnotes
Unleash the topper in you