



Drought-Proofing Agriculture: Crop Production Strategies under El Niño Conditions

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Rainfall variability associated with large-scale climate phenomena such as El Niño can increase production risks in rainfed agriculture by altering the timing, intensity and distribution of rainfall. The impact of a dry season on crop productivity is determined not only by seasonal rainfall deficiency but also by soil-water storage, atmospheric evaporative demand, crop duration and the occurrence of moisture stress during critical growth stages. This is particularly relevant to Tamil Nadu, where the northeast monsoon contributes substantially to agricultural water availability. Recent research from Tamil Nadu and other parts of India has demonstrated that broad-bed and furrow land configuration, crop-residue mulching, moisture-retaining materials, targeted foliar nutrition and physiological stress-mitigation treatments can improve crop performance under water-limited conditions. In rice, moisture stress during panicle initiation can cause substantial yield losses, whereas selenium application at heading has shown potential for reducing drought-induced damage in aerobic rice. In blackgram, integrated use of broad-bed and furrow cultivation, crop-residue mulch and physiological stress-management treatments improved productivity under moisture stress. Drought-proofing agriculture therefore requires a crop-specific combination of soil, water, nutrient and physiological management rather than a single drought-control measure.

Keywords: El Niño, agricultural drought, moisture stress, rainfed agriculture, soil-water conservation, crop-residue mulch, foliar nutrition, water-use efficiency, climate-resilient agriculture, crop production.

Introduction

Agricultural production in rainfed regions is closely dependent on the amount and temporal distribution of rainfall. A crop may receive adequate seasonal rainfall and still experience severe moisture stress when rainfall is concentrated within a few intense events followed by prolonged dry periods. Such rainfall distribution reduces the proportion of precipitation retained within the effective root zone and increases dependence on stored soil moisture. The problem becomes more pronounced when high temperature and atmospheric evaporative demand accelerate depletion of available water. Consequently, drought management needs to consider not only seasonal rainfall deficiency but also the duration of dry spells, soil-water storage and the coincidence of moisture stress with sensitive crop stages. El Niño is an important component of the climate system that can influence atmospheric circulation and rainfall patterns over India. Its relationship with Indian rainfall is not uniform or deterministic, but the associated climate variability makes it relevant to agricultural risk assessment. This relationship is particularly important in Tamil Nadu because the northeast monsoon contributes substantially to annual rainfall. Recent analysis of coastal Tamil Nadu rainfall during 1901–2020 examined the association between El Niño Southern Oscillation and northeast monsoon rainfall and emphasized the relevance of large-scale climate variability to regional rainfall assessment (Lakshmi *et al.*, 2025).

The agricultural consequences of drought are determined largely by the availability of water in the crop root zone. Rainfall received at the soil surface may be lost through runoff, evaporation and deep percolation before it becomes available to plants. Soil texture, organic matter, surface cover, field slope, infiltration characteristics and rooting depth influence the proportion of rainfall that can be stored and subsequently utilized. The timing of moisture stress is equally important. A recent field experiment at Coimbatore demonstrated that 20 and 25 days of moisture stress beginning at panicle initiation reduced rice grain yield by 56.2 and 58.0%, respectively, compared with irrigated conditions (Patnaik *et al.*, 2025).

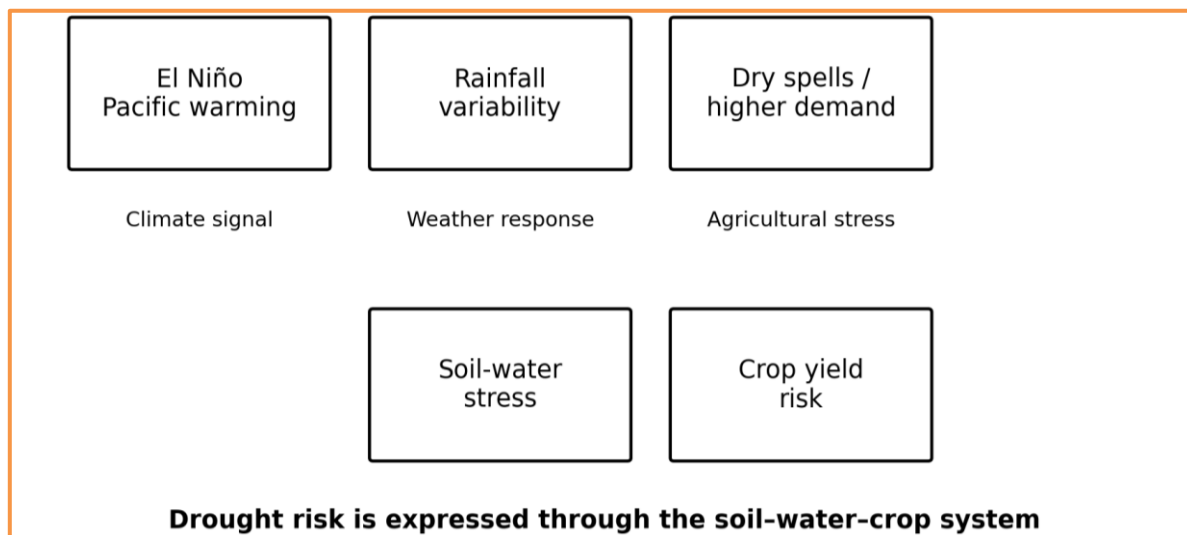


Figure 1. Conceptual relationship between El Niño-related rainfall variability, soil-water stress and crop-production risk.

Crop Planning and Establishment under Rainfall Uncertainty

The first component of drought-resilient crop production is matching crop duration and water requirement with the expected period of soil-water availability. When rainfall onset is delayed or the effective growing period becomes shorter, long-duration crops remain exposed to terminal drought for a greater proportion of their life cycle. Short-duration crops and early-maturing cultivars can reduce this exposure by completing reproductive development within a shorter period. Crop diversification further distributes climatic risk because cereals, millets, pulses and oilseeds differ in rooting depth, duration and sensitivity to moisture stress. Intercropping can also improve production stability by combining crops with different growth patterns and resource requirements. Such systems should be selected according to local rainfall, soil type and crop compatibility rather than applying a fixed combination across all environments. Uniform crop establishment is equally important because an uneven plant stand cannot utilize later rainfall efficiently. Seed quality, sowing depth, plant population and sowing immediately after an effective rainfall event influence establishment under moisture-limited conditions. Seed-hardening treatments have been investigated for improving early establishment and tolerance to subsequent moisture limitation, but their concentration and duration are crop-specific and should be based on validated experimental evidence. Seed treatment should therefore be integrated with rainfall-based sowing rather than considered a substitute for adequate seed-zone moisture.

In-situ Soil-Water Conservation

The effectiveness of rainfall in crop production depends substantially on the amount of water that infiltrates and remains within the effective root zone. Broad-bed and furrow cultivation, compartmental bunding, ridge-and-furrow systems and conservation furrows can reduce runoff and improve infiltration according to soil type and crop requirement. A field experiment conducted at Kovilpatti, Tamil Nadu, demonstrated that broad-bed and furrow cultivation increased blackgram grain yield from 390 to 459 kg ha⁻¹ compared with flat-bed cultivation and improved rainfall-use efficiency from 2.71 to 3.81 kg ha⁻¹ mm⁻¹.

(Subbulakshmi *et al.*, 2024). The result demonstrates that improving field geometry can increase the utilization of rainfall without increasing the rainfall received. The effectiveness of land configuration can be strengthened through residue retention. Crop residues reduce the velocity of runoff, protect the soil surface and improve the opportunity for rainfall infiltration. Research in rainfed groundnut under semi-arid conditions has also demonstrated that suitable seedbed preparation combined with crop-residue mulch can improve soil moisture conservation and rainwater-use efficiency (Pandian *et al.*, 2021).

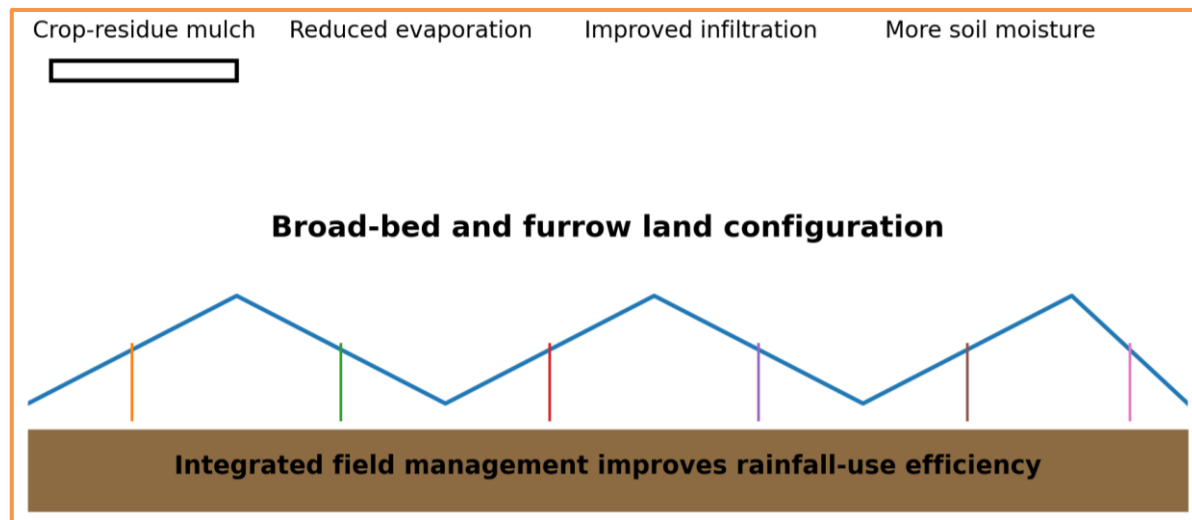


Figure 2. Schematic representation of broad-bed and furrow land configuration integrated with crop-residue mulch for soil-water conservation.

Crop-Residue Management and Mulching

Mulching reduces direct evaporation from the soil by creating a protective layer between the soil surface and the atmosphere. Paddy straw, sorghum residues, maize stalks and other locally available crop biomass can be retained on the soil surface when they are not required for livestock feed or other essential uses. In addition to reducing evaporation, residue mulch moderates soil temperature, reduces surface crusting and contributes organic matter as it decomposes. The Kovilpatti blackgram experiment evaluated crop-residue mulch at 5 t ha^{-1} as one component of a drought-mitigation programme. Sorghum, maize and minor-millet straw were used as mulch material, and the study demonstrated the benefit of integrating residue mulch with broad-bed and furrow cultivation and physiological stress-management treatments (Subbulakshmi *et al.*, 2024). In rainfed groundnut, residue mulch combined with appropriate seedbed preparation also improved soil-water conditions (Pandian *et al.*, 2021). Plastic mulch can provide stronger physical protection in high-value crops, but its additional cost and disposal requirements should be considered before adoption.

Strategic Water Management during Critical Crop Stages

Water requirement is not uniform throughout the crop life cycle, and the yield penalty associated with moisture stress varies among developmental stages. Consequently, limited irrigation water should be allocated according to crop sensitivity rather than distributed uniformly throughout the season. In rice, panicle initiation is particularly sensitive; the Coimbatore study showed that prolonged stress during this stage produced much greater yield penalties than stress imposed at flowering (Patnaik *et al.*, 2025). In groundnut, recent research has shown that late-stage moisture stress can cause severe reductions in pod yield, emphasizing the importance of maintaining soil moisture during reproductive development (Radha Kumari *et al.*, 2026).

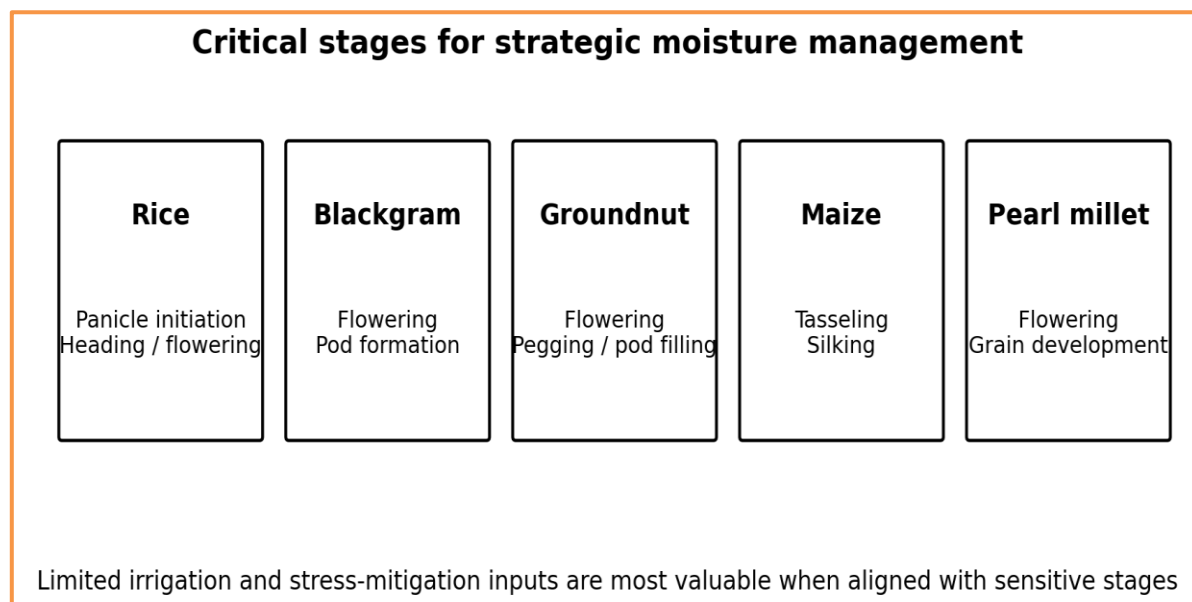


Figure 3. Major crop growth stages at which moisture conservation and limited irrigation are particularly important

Crop-Specific Drought Mitigation

Rice

Rice production under uncertain rainfall requires particular attention to moisture availability during reproductive development. A field experiment at Coimbatore evaluated 8- and 12-day drought periods beginning at heading and tested salicylic acid at 100 ppm, sodium selenate at 20 ppm and PPFM at 1%. Sodium selenate at 20 ppm produced beneficial effects on physiological parameters, yield attributes and water-use efficiency, and the yield reduction under an 8-day drought period was 16.5% compared with the corresponding fully irrigated treatment receiving selenium (Senthil Kumar *et al.*, 2024). The study demonstrates that physiological stress mitigation can complement, but not replace, appropriate irrigation management during a short-duration drought.

Blackgram

Blackgram is widely grown under rainfed conditions but remains sensitive to moisture stress during flowering and pod development. At Kovilpatti, treatments included broad-bed and furrow cultivation, Pusa hydrogel at 5 kg ha⁻¹, crop-residue mulch at 5 t ha⁻¹, PPFM at 1% and KCl at 1%, with foliar treatments applied at 30 and 45 DAS. The combination of broad-bed and furrow cultivation, Pusa hydrogel at 5 kg ha⁻¹, crop-residue mulch at 5 t ha⁻¹ and PPFM at 1% produced approximately 480 kg ha⁻¹ grain yield under moisture-stress conditions (Subbulakshmi *et al.*, 2024). Economic performance differed from biological performance because hydrogel increased input cost, highlighting the importance of evaluating both yield response and economic feasibility.

Groundnut

Groundnut is particularly sensitive to water shortage during flowering, pegging and pod development. Research under semi-arid conditions has shown that residue mulch combined with appropriate seedbed preparation improves rainwater-use efficiency (Pandian *et al.*, 2021). Recent raised-bed research also evaluated mulch and foliar zinc management; plastic mulch combined with 0.5% ZnSO₄ at 40 DAS produced approximately 2,471 kg ha⁻¹ pod yield under the experimental conditions (Mahanthesha *et al.*, 2024). Where plastic mulch is not economically feasible, locally available crop residues provide a lower-cost alternative.

Pearl millet and sorghum

Pearl millet and sorghum possess inherent adaptation to dry environments, but productivity can still be reduced by severe or prolonged moisture stress. Recent pearl millet research evaluated straw mulch at 3 t ha⁻¹ and Pusa hydrogel at 2.5 and 5 kg ha⁻¹ together with zinc management. Hydrogel at 5 kg ha⁻¹ produced the highest grain yield among the moisture-

management treatments, while a lower rate provided greater economic efficiency; soil application of $12.5 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O ha}^{-1}$ followed by a 0.5% ZnSO_4 foliar spray at maximum tillering also improved crop performance (Vikramarjun *et al.*, 2025). Research in early-maturing rabi sorghum has identified physiological traits associated with improved drought tolerance, supporting the use of suitable early-maturing material in moisture-limited environments (Patroti *et al.*, 2023).

Weed Management under Moisture-Limited Conditions

Weed competition becomes particularly important when rainfall is deficient because weeds consume water from the same limited soil reservoir used by the crop. Early weed management therefore contributes directly to soil-water conservation. Recent research in dry direct-seeded rice evaluated sequential herbicide programmes and found that pendimethalin at 0.75 kg ha^{-1} as a pre-emergence treatment followed by bispyribac sodium at 0.25 kg ha^{-1} as a post-emergence treatment effectively reduced weed density and biomass (Dhillon *et al.*, 2026). In blackgram, research at S.V. Agricultural College, Tirupati, evaluated new-generation herbicides and reported effective weed suppression with diclosulam at 20 g ha^{-1} followed by one hand weeding at 15 DAS; fluazifop-p-butyl + fomesafen at 222 g ha^{-1} also produced yields comparable with twice-hand-weeded plots under the experimental conditions (Sreekanth *et al.*, 2024). Herbicide selection should always follow the registered formulation, crop label and locally validated recommendations.

Foliar Nutrition and Physiological Stress Management

Moisture stress can restrict nutrient uptake through the roots, particularly when soil-water availability becomes low. Foliar nutrition can provide an alternative route for supplying specific nutrients during temporary stress, but its effectiveness depends on crop, growth stage, concentration and severity of drought. In blackgram, 1% KCl and 1% PPFM were evaluated at 30 and 45 DAS and produced measurable improvements in yield and economic returns under moisture stress (Subbulakshmi *et al.*, 2024). In aerobic rice, 20 ppm sodium selenate at heading reduced the detrimental effects of short-duration drought (Senthil Kumar *et al.*, 2024). In groundnut, 0.5% ZnSO_4 at 40 DAS improved productivity when combined with suitable mulch management (Mahanthesha *et al.*, 2024). These findings emphasize the importance of using crop-specific, experimentally validated concentrations rather than treating foliar sprays as universal drought remedies.

Integrated Drought-Resilient Crop Production

Drought resilience is most effectively developed by combining technologies that address different components of the soil-water-crop relationship. Land configuration improves rainfall infiltration, residue mulch reduces evaporation, weed control limits unnecessary water consumption, strategic irrigation protects sensitive growth stages and foliar treatments can support physiological functioning during temporary stress. The blackgram experiment at Kovilpatti demonstrated that combinations of broad-bed and furrow cultivation, residue mulch and physiological stress-management treatments can perform better than individual interventions (Subbulakshmi *et al.*, 2024). Similar principles can be applied to groundnut, pearl millet, rice and other rainfed crops, with the specific technologies selected according to crop and soil conditions.

The economic feasibility of drought-management technologies should receive equal attention. Hydrogel and plastic mulch may provide substantial biological benefits in experimental conditions, but locally available crop residues and conservation land configuration can provide lower-cost alternatives. A practical drought-resilient package should therefore be based on scientific effectiveness, economic return, availability of materials and compatibility with the existing farming system.

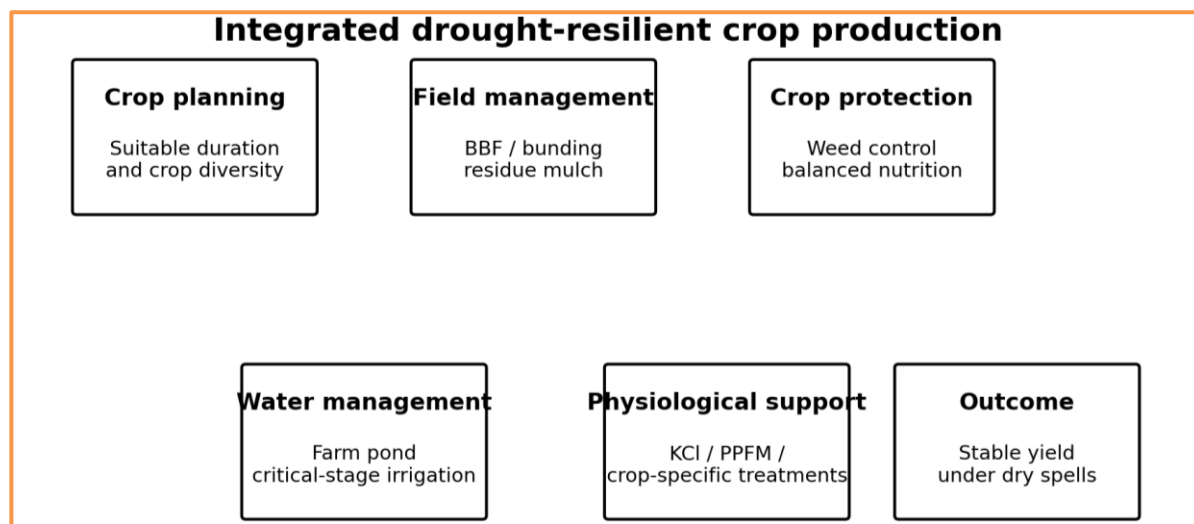


Figure 4. Integrated framework for drought-resilient crop production combining crop planning, field management, water management and physiological support

Conclusion

Drought-proofing agriculture under El Niño-associated rainfall variability requires a shift from reactive drought response to proactive crop-water management. The objective is to improve rainfall capture, retain soil moisture, minimize unnecessary water loss and protect the crop during growth stages that contribute most directly to yield formation. Recent Indian research provides evidence for broad-bed and furrow cultivation, crop-residue mulch, hydrogel, KCl, PPFM, selenium, zinc and strategic irrigation as components of crop-specific drought-management systems. The most appropriate combination will differ among crops and agro-ecological situations, but the underlying principle remains consistent: rainfall should be conserved within the field, soil moisture should be protected from avoidable depletion and limited irrigation should be prioritized for sensitive developmental stages.

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