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SOYBEAN PRODUCTIVITY AND YIELD STABILITY UNDER WATER-LIMITED CONDITIONS: EVIDENCE FROM CENTRAL ASIA

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Abstract
Soybean is increasingly viewed as a strategic crop for Central Asia because it combines high-quality protein with nitrogen fixation, supports crop-rotation benefits, and can reduce dependence on imported oilseed products. Yet soybean productivity in the region is strongly constrained by water scarcity, high evaporative demand, and growing climate variability. This article synthesizes evidence on soybean yield formation and yield stability under water-limited conditions in Central Asia, with emphasis on irrigated–non-irrigated contrasts, drought escape via maturity group selection, and drought tolerance traits targeted by breeding.

Keywords: Soybean; drought stress; yield stability; water-limited agriculture; Central Asia; irrigation efficiency; genotype.

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INTRODUCTION

Central Asia is entering an era in which "average" hydrology is no longer a safe planning assumption. Rising temperatures, higher evaporative demand, increasing frequency of heatwaves, and more variable precipitation patterns are intensifying competition for irrigation water across agriculture, ecosystems, and energy needs. Regional assessments emphasize that water scarcity is already a major risk in parts of Asia, including Central Asia, and cross-boundary adaptation is critical because many water systems depend on upstream glaciers and transboundary rivers. In such settings, the productivity of irrigated crops is increasingly determined by how effectively each unit of water is converted into harvestable yield, and how resilient that yield remains in dry years [1].

Soybean (Glycine max (L.) Merr.) is widely recognized for its high protein and oil content, its role in diversifying rotations, and its ability to fix atmospheric nitrogen, improving soil fertility and lowering fertilizer requirements. For Central Asia, soybean expansion is appealing for three reasons. First, it can strengthen domestic supplies of plant protein and edible oil, reducing import dependence. Second, it can provide a rotational break that supports cereal and vegetable systems through better soil structure and nutrient cycling.

MATERIALS AND METHODS

Against this backdrop, the key question is not simply "Can soybean yield be increased?" but "Can soybean yield be stabilized?" Yield stability is central for farm income, supply-chain reliability, and national food-security planning. In practice, stability depends on the interaction of genetics (drought tolerance and drought escape), agronomy (sowing date, plant density, rhizobial inoculation, fertility, pest management), and water governance (irrigation scheduling, conveyance efficiency, allocation rules). A useful way to structure this problem is through genotype × environment (G×E) frameworks and stability parameters, which quantify how consistently a genotype performs across diverse

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environments and stress levels. The classical stability approach developed by Eberhart and Russell remains influential because it captures both responsiveness to environmental improvement and deviations from predictable performance—concepts directly relevant to water-limited farming [2].

This article therefore reviews and integrates evidence on soybean productivity and yield stability under water-limited conditions in Central Asia. We highlight (i) the regional water constraint context and why it is tightening; (ii) the physiological pathways through which water deficits reduce yield and increase variability; (iii) emerging field and genetic evidence from Kazakhstan as a proxy for broader Central Asian agroecological patterns; and (iv) an integrated management pathway that balances yield potential with stability and risk reduction.

RESULTS AND DISCUSSION

Water limitation in Central Asia is not only a meteorological issue; it is also a systems issue shaped by infrastructure, allocation rules, and soil constraints. A regional review on irrigation and water conservation notes substantial losses from canal systems and widespread salinization on irrigated lands, both of which reduce the effective water available for crops and depress yield response to irrigation. From a soybean perspective, this means that "applied" irrigation water is often not equal to "effective" root-zone water, and that salinity can amplify drought stress by restricting water uptake and increasing osmotic pressure. Thus, even in irrigated districts, soybean may face intermittent water stress during critical phenological windows if delivery reliability is low or if on-farm application is inefficient [2].

The climate signal further compounds these constraints. IPCC assessments emphasize that climate change is altering the water cycle and increasing water-related risks, with implications for irrigation-dependent systems. In practical terms, warmer conditions increase crop water demand (via higher

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evapotranspiration), and drought episodes can become both more frequent and more intense. For soybean, the timing of stress is decisive: deficits during vegetative growth may reduce canopy development, but deficits during flowering and early pod set can reduce reproductive success sharply, while deficits during seed filling reduce seed size and final yield. This sensitivity explains why the same seasonal rainfall total can produce different yields depending on rainfall distribution and the reliability of supplementary irrigation.

A growing body of evidence from Kazakhstan—one of the region's most active soybean research contexts—illustrates how genotype choice interacts with water limitation. A recent field-trial study evaluated soybean genotypes under well-watered and non-irrigated conditions in very dry environments and focused on drought tolerance and "drought escape" mechanisms linked to maturity groups. The concept of drought escape is particularly relevant for Central Asia: if late-season water becomes unreliable, earlier-maturing cultivars can complete seed filling before severe stress peaks. However, early maturity can come with trade-offs such as reduced biomass accumulation and potentially lower maximum yield in favorable years. The practical implication is that stability-oriented cultivar selection may favor genotypes that do not always top yield charts in wet conditions but avoid catastrophic declines in dry years [4].

CONCLUSION

Soybean has genuine potential to strengthen Central Asia's agricultural diversification and protein security, but in water-limited environments its success depends on achieving not only higher yields, but more reliable yields. Evidence from recent field trials and genetic analyses in Kazakhstan demonstrates that soybean genotypes differ substantially in their responses to irrigation scarcity and drought, and that maturity-group strategies can support drought escape while breeding targets drought tolerance for longer-term gains. However, genetics alone is insufficient. Water limitation in Central Asia is shaped by climate risk,

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transboundary hydrology, infrastructure losses, and salinity—factors that can amplify variability and undermine productivity unless addressed as a system.

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