



RESEARCH ARTICLE

Effect of Soil Moisture Levels (Drought vs. Well-Watered) on Seed Germination and Seedling Growth

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ARTICLE INFO

Article History:

Received 13 June, 2026

Received in revised form 21 June, 2026

Accepted 30 June, 2026

Published online 20 August, 2026

Keywords:

Drought stress

Field capacity

Seed germination

Soil moisture

Seedling growth

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ABSTRACT

Seedling establishment and, therefore, crop productivity is influenced by water availability at early growth stages. The effects of three soil moisture treatments, well-watered (80–100% field capacity; FC), moderate drought (50% FC) and severe drought (25% FC), on seed germination and early seedling growth of common bean (*Phaseolus vulgaris* L.) in controlled pot-culture conditions were studied. The germination percentage, mean germination time and germination index were measured during a 10-day period after sowing, while growth parameters of seedlings (shoot and root length, dry biomass, relative water content) were measured at 21 DAS. The percentage of germination and the speed of germination were significantly decreased with soil water deficit and became less than half of that in the well-watered controls in severe drought conditions. Shoot elongation and total biomass accumulation were also severely reduced under drought stress, whereas root length had a slight increase during moderate drought, suggesting drought avoidance strategy as an increase in root length in order to access water from deeper layers; this was not consistent during severe drought as the overall growth was down. The RWC decreased gradually as the water deficit increased, indicating dehydration of cells and loss of turgor. The results support the assumption that soil moisture availability is one of the most significant constraints for seed germination and establishment and can have implications for irrigation scheduling, seed-bed management and the variety or cultivar selection in water-limited agricultural systems.

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1. Introduction

Seed germination and establishment of seedlings are very critical stages in the plant life cycle that require water. Imbibition needs sufficient soil moisture to activate metabolic enzymes and mobilize stored reserves in the seed; sufficient water availability during the subsequent seedling growth will facilitate cell expansion, turgor-driven elongation, and photosynthetic development. Under drought stress (where available soil water is insufficient to meet plant demand), these processes can be affected and drought stress is one of the most important abiotic limitations of global agricultural productivity [1,2].

In many agricultural areas, climate change is expected to lead to more frequent, more intense and longer droughts, necessitating a better understanding of the impact of water deficit for the initial and most vulnerable phases of crop growth. Low soil moisture exposure may lead to delayed and/or poor germination caused by inadequate imbibition and

osmotic stress; drought-exposed seedlings may have reduced shoot growth and changes in root morphology as well as reduced tissue water status [3].

Plants have developed several physiological and morphological adaptations to deal with water-stressed conditions [4]. One of the most common drought-avoidance strategies is to allocate resources for root growth rather than shoot growth, thus resulting in an increase in the root/shoot ratio and making deeper soil water available. When conditions are so critical or prolonged, however, these compensatory mechanisms are not enough, resulting in overall growth suppression, lower relative water content and in extreme cases, seedling mortality [5,2].

Although the general trend of decrease in plant growth with drought stress is well known, it is important to determine the specific point in which water shortage becomes moderate rather than severe for the purpose of irrigation scheduling, direct seeding and cultivar selection in water-limited production systems [6,5]. The aim of this study is therefore

to compare in a systematic way the germination and early seedling growth responses of bean seedlings when subjected to the moisture gradient ranging from well-watered to very drought-stressed soil moisture conditions.

2. Materials and Methods

2.1 Plant Material and Soil Preparation

Seeds of common bean (*Phaseolus vulgaris* L. cv. All the plants ('Contender') were surface-sterilized using 1% sodium hypochlorite for 5 minutes and thoroughly washed with distilled water. The potting substrate used in this experiment was a sandy-loam that was oven-dried and then gravimetrically measured for field capacity (FC), which is the water held by the soil when it is no longer being subject to gravitational drainage. The pots used (15 cm diameter) were prepared with a uniform amount of the dried substrate, and moistened to the desired water content for each treatment before seeding.

2.2 Soil Moisture Treatments

Three soil moisture regimes were created, well-watered (WW, 80–100% FC, control), moderate drought (MD, 50% FC) and severe drought (SD, 25% FC). Soil moisture was gravimetrically sampled every 2 days and water was added to the soil at each sampling to keep each treatment within its desired range during the experiment. A total of 10 seeds was planted in each pot and 15 pots were used per treatment (n = 15). Details of treatment are summarized in Table 1.

2.3 Germination Assessment

Germination was considered as the appearance of the radicle ≥ 2 mm and was observed daily for 10 days after sowing. The percentage of germination, mean germination time and germination index were determined by the standard formula using the number of seeds that germinated every day.

Table 1. Summary of soil moisture treatments and irrigation regimes.

Treatment	Soil Moisture Level	Target Capacity (%)	Field Capacity (%)	Irrigation Regime
WW	Well-watered (control)	80–100%		Watered to field capacity every 2 days
MD	Moderate drought	50 $\pm$ 5%		Watered to 50% FC every 3 days
SD	Severe drought	25 $\pm$ 5%		Watered to 25% FC every 4 days

2.4 Seedling Growth Measurements

Seedlings were carefully removed from the pots at 21 days after sowing and the roots were washed free from soil. The length of the shoots (from the ground level to the shoot apex) and the length of the roots (from the ground level to the root tip) were determined by using a ruler. The total dry weight of the seedlings was then measured after being oven dried for 48 hours at 70 °C.

2.5 Relative Water Content (RWC)

The relative water content of leaves was determined by using fully expanded leaves from each treatment. The fresh weight (FW) was collected immediately after slicing the leaves into discs, the turgid weight (TW) was collected after floating leaf discs in distilled water for 24 hours at 4 °C, and the dry weight (DW) was collected after drying leaf discs in the oven at 70 °C for 48 hours. RWC was calculated as: $RWC (\%) = [(FW - DW) / (TW - DW)] \times 100$.

2.6 Experimental Design and Statistical Analysis

The experiment was laid out in a completely randomized design (CRD) having 15 pots per treatment and 3 treatments. A one-way analysis of variance (ANOVA) was used to analyze the data and treatment means were separated by Tukey's Honestly Significant Difference (HSD) test at the 0.05 level of significance. All statistical analysis was done with the use of common statistical software. Values are given as mean $\pm$ standard error (SE); means with different superscript letter in a column are significantly different.

3. Results

3.1 Seed Germination

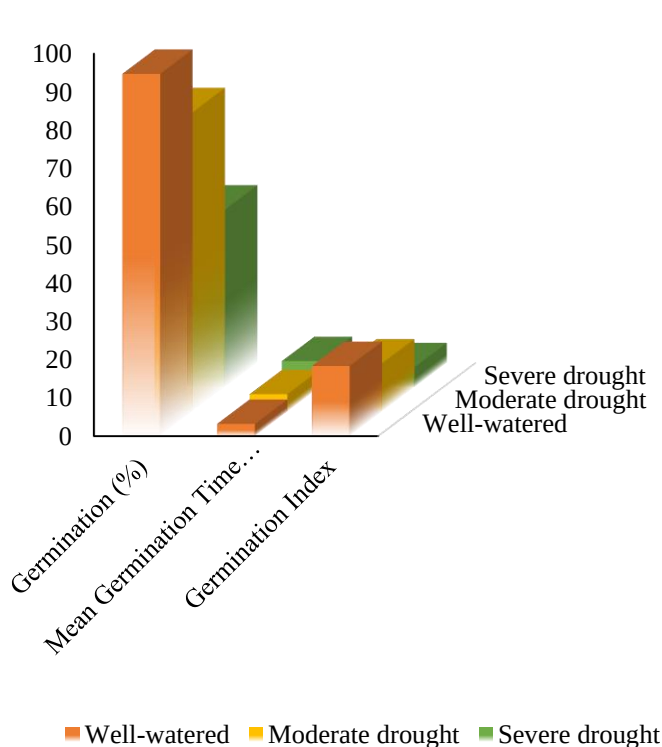
All the germination parameters were significantly affected ($p < 0.05$) by soil moisture level. The well-watered seeds had the highest final germination percentage ($94.7 \pm 2.1\%$) which was significantly higher than the moderate drought ($78.3 \pm 3.0\%$) and severe drought ($46.5 \pm 3.6\%$). Water-deficit conditions also caused significant delays to germination with the mean germination time rising from 3.2 ± 0.2 days with well-watered conditions to 6.9 ± 0.4 days under severe drought. The germination index (GI) decreased as soil moisture decreased, showing that as soil moisture levels decreased, germination rate and uniformity decreased. The germination data are summarized in Figure 1.

3.2 Seedling Growth

All the germination parameters were significantly affected ($p < 0.05$) by soil moisture level. The well-watered seeds had the highest final germination percentage ($94.7 \pm 2.1\%$) which was significantly higher than the moderate drought ($78.3 \pm 3.0\%$) and severe drought ($46.5 \pm 3.6\%$). The mean germination time was also significantly increased in water-deficit situations compared to well-watered situations, from 3.2 ± 0.2 days to 6.9 ± 0.4 days, respectively. The germination index (GI) decreased with decrease of soil

moisture level indicating a reduction in germination rate and uniformity with decrease in soil moisture. The mean germination results are summarized in Figure 2.

Figure 1. Germination parameters of bean seeds under different soil moisture treatments over a 10-day period (mean $\pm$ SE, n = 15).



3.3 Relative Water Content

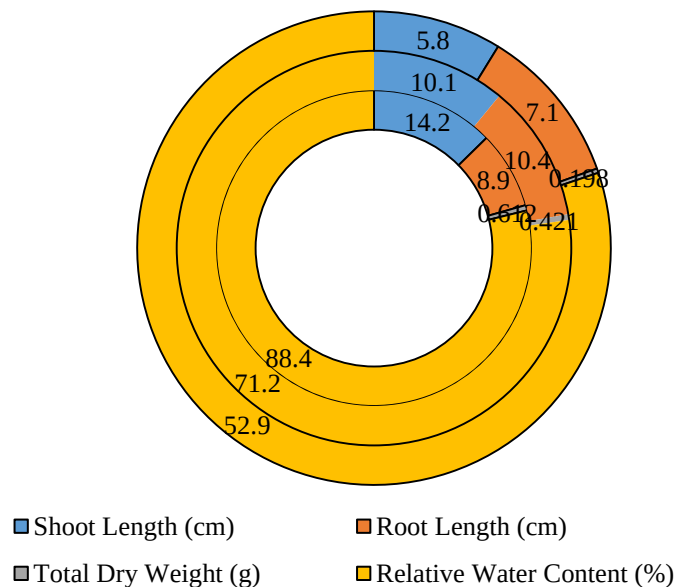
The RWC values were reduced steadily with the soil water deficit from wet conditions ($88.4 \pm 1.6\%$) to moderate drought ($71.2 \pm 2.0\%$) to severe drought ($52.9 \pm 2.4\%$). The trend was noted as a decrease in cellular hydration and turgid pressure is proportional to the soil moisture availability and was closely related to the decrease in shoot growth and biomass accumulation.

4. Discussion

This study validates the dose-dependent effect of soil moisture availability on seed germination and early seedling growth. This decrease in germination percentage and rate of germination under drought stress is in agreement with the physiological need of adequate uptake of water for imbibition and activation of hydrolytic enzymes to release stored seed reserves [7]. The lower final germination percentage and longer mean germination time with drought treatments were explained by the reduced osmotic gradient causing water movement into the seed at low soil water potential, which

results in reduced metabolic reactivation required for radicle emergence [8].

Figure 2. Seedling growth and water status parameters at 21 days after sowing under different soil moisture treatments (mean $\pm$ SE, n = 15).



A differential response to drought stress seen in shoot and root growth is a well-documented plant strategy in dealing with low water availability. The relative increase in root length observed in the present study is in accordance to the hormonally induced changes in resource allocation as a consequence of moderate water deficit, which results in limited cell expansion in the shoot but less inhibition in the root, thus enabling the root system to probe a greater soil volume for water [2,9]. This drought-avoidance response is commonly observed in the cereal and legume crops and is usually linked to the buildup of abscisic acid (ABA) that prevents shoot growth, but at moderate intensities of stress, root elongation is less inhibited, or even stimulated [10]. The observed reduction in RWC and complete absence of the compensatory root response during severe drought indicates that there may be a threshold beyond which all growth processes, including root elongation, become water content-limited. [11] This fits into the general idea that drought-avoidance traits will be effective only under specific water stress, at which point drought-tolerance traits (such as dehydrin accumulation, antioxidant defence and osmotic adjustment) will become important for the survival of the seedling, which were not measured in this study. Applied point of view, these findings have direct implications for the agricultural practice. The significant decrease in germination and vigour in seedlings in response to moderate drought stress (50% field capacity) indicates the need for

adequate seed-bed moisture at planting time, especially in rain-fed or water stress situations [12,13]. The outcomes further validate the breeding or selection of drought-tolerant cultivars with efficient root systems and osmotic adjustment ability, and the benefit of soil moisture conserving practices like mulching, less tillage and use of water-retentive soil amendments to buffer against short term water deficits during the critical germination and establishment phase [12].

5. Conclusion

The results of this study prove that soil moisture availability is one of the most important factors affecting seed germination and early seedling growth, and further shows that the water stress progressively decreases the germination percentage, the speed of the germination process, the growth of shoots and the accumulation of biomass, and lowers the relative water content of the seedlings. A moderate drought induced a compensatory root elongation, characteristic of a drought-avoidance strategy, while under severe drought overall growth was widely reduced. The results highlight the need to ensure sufficient levels of soil moisture during crop establishment and the value of agronomic practices that preserve moisture and drought-tolerant cultivars for water-constrained production systems.

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