Molecular Soil Biology 2025, Vol.16, No.6, 306-313
http://bioscipublisher.com/index.php/msb

Case Study Open Access

Yield Performance of Potato Varieties Under Different Irrigation Regimes

Keyan Fang [1], Zhongmei Hong [2]
1 Institute of Life Science, Jiyang College of Zhejiang AandF University, Zhuji, 311800, China
2 Hainan Provincial Institute of Biological Engineering, Haikou, 570206, Hainan, China
Corresponding email: keyan.fang@jicat.org
Molecular Soil Biology, 2025, Vol.16, No.6 doi: 10.5376/msb.2025.16.0028
Received: 04 Oct., 2025
Accepted: 11 Nov., 2025
Published: 04 Dec., 2025

Preferred citation for this article:
Fang K.Y., and Hong Z.M., 2025, Yield performance of potato varieties under different irrigation regimes, Molecular Soil Biology, 16(6): 306-313 (doi: 10.5376/msb.2025.16.0028)

Abstract As water resources become more limited and climate conditions keep changing, good irrigation planning is very important for stable potato yield. This study compared yield performance under full irrigation, mild deficit irrigation, and moderate to severe deficit irrigation. Potato varieties with different maturity types and different genetic backgrounds were tested. Differences in water use efficiency were also analyzed. The response of potato to water supply was clearly different among varieties and also varied at different growth stages. Different varieties use different ways to adapt to low water conditions. Matching suitable potato types with proper irrigation methods, and applying moderate deficit irrigation during non-critical growth stages, can help save water while keeping stable yield. This also improves potato adaptation to climate change.
Keywords Potato (*Solanum tuberosum* L.); Deficit irrigation; Varietal differences; Yield components; Water use efficiency

1 Introduction

The potato (*Solanum tuberosum* L.) is the third most important food crop in the world, after wheat and rice, and is cultivated in more than 100 countries (Birch et al., 2012). With the continuous growth of the global population, the increasingly limited arable land resources and the intensifying climate change, how to maintain a stable potato yield under the condition of limited water resources has become a key issue (Djaman et al., 2021; Ahmed et al., 2023). The yield of potatoes is highly sensitive to the time and place of water supply. Water supply at different growth stages directly affects photosynthesis, tuber initiation, and tuber bulking (Jama-Rodzenska et al., 2021; Wagg et al., 2021; Mora-Sanhueza et al., 2025; Rai et al., 2025).

From the view of food security, potato produces high calories per unit area and has a short growth cycle. It can give high and stable yields in many ecological regions. For this reason, it is an important crop for reducing food shortages and seasonal hunger in developing countries (Degebasa, 2019; Degebasa, 2020). In mountain and highland areas such as Nepal and Ethiopia, potato has become one of the main foods for local people. It is seen as a key crop to improve food and nutrition security for small farmers (Bajracharya and Sapkota, 2017; Moreda et al., 2022). In many arid and semi-arid regions, irrigation water has approached or even exceeded the sustainable supply level of water resources (Balasubramanya et al., 2022; Lakhiar et al., 2024). With the intensification of climate change, precipitation has become more unstable, and the demand for crop evapotranspiration has been increasing continuously, intensifying the pressure and risks on water resources for agricultural production (Nikolaou et al., 2020; Ahmed et al., 2023). In regions with scarce water resources, precision irrigation and intelligent irrigation technologies are being promoted at a faster pace.

This study mainly focuses on the yield differences of potato varieties under different irrigation conditions. By setting multiple irrigation gradients, the yield changes and water use efficiency of representative potato varieties at different water levels were compared. Meanwhile, analyze the influence of irrigation levels on the main yield components such as the number of tubers formed, the weight of individual tubers, and the commercialization rate. Based on a comprehensive consideration of "increased production" and "water conservation", irrigation optimization suggestions that are in line with local water resource conditions are put forward, providing references for water conservation and efficiency improvement in regional potato production and response to climate change.

2 Description of the Study Area and Experimental Conditions

2.1 Geographic location and climatic characteristics

In arid areas of northwest China, such as the Hexi Oasis irrigation zone, the main potato growing period is from April to September. The average temperature in July is around 20 ℃. The climate is typical temperate continental or semi-arid monsoon type. It has large day–night temperature differences and high evaporation demand. According to the data from 87 meteorological stations in Gansu Province over the past 50 years, potatoes need water the most in June and July. The average rainfall in these two months was only 140 millimeters. For every additional millimeter of rainfall, the yield of potatoes can increase by 30 to 60 kilograms per hectare (Lu et al., 2025). At the same time, the average July temperature has increased at a rate of 0.55 ℃ per decade. The annual accumulated temperature above 10 ℃ reaches 2 917 ℃. This means heat resources are generally enough, and rainfall becomes the main limiting factor. The temperature in February and March had a significant impact on the sowing time of spring potatoes at 12 locations in South Korea. During the main growing period from April to June, the differences in temperature and rainfall among various regions are relatively small. The yield range is 22.5 to 35.0 t/ha. Under the humid temperate climate conditions, the balance of climatic conditions during the growing season can reduce the yield differences between regions (Park et al., 2025).

2.2 Soil properties

In the oasis areas of northwest China and some irrigated agricultural areas in Africa, the soil in these regions is mostly deep sandy loam or sandy clay loam. This type of soil has good water permeability and also possesses a certain water retention capacity (Li et al., 2025; Sande et al., 2025). In the Tsangano and Angonia regions of Mozambique, the four typical soil profiles investigated all fall within the range of sandy loam to sandy clay loam. The thickness of the soil layer is generally over 150 centimeters, and the soil bulk density ranges from 0.78 to 1.30 Mg/m³. Among them, the effective water holding capacity of the TSA-P02 profile is relatively high, reaching 182 mm/m.In terms of chemical properties, the pH values of these soils range from 5.6 to 7.9, and the cation exchange capacity is 10.1 to 11.33 cmol(+)/kg. Due to the low nutrient levels, this type of soil is generally classified as "barely suitable" (S3f). Although the physical conditions of the soil are good and its water supply capacity is strong, insufficient fertility remains the main limiting factor. Nutrient management must be strengthened in the later stage (Sande et al., 2025) (Figure 1). At the national scale in Slovakia, major potato production areas are mainly Cambisols, Chernozems, and Fluvisols. Soil texture is mostly loam, with 30%~45% particles smaller than 0.01 mm. Soil depth is greater than 0.6 m, and slope ranges from 0 to 3°. This soil combination provides good aeration and high water-holding capacity and is classified as the most suitable type (Koco et al., 2020).

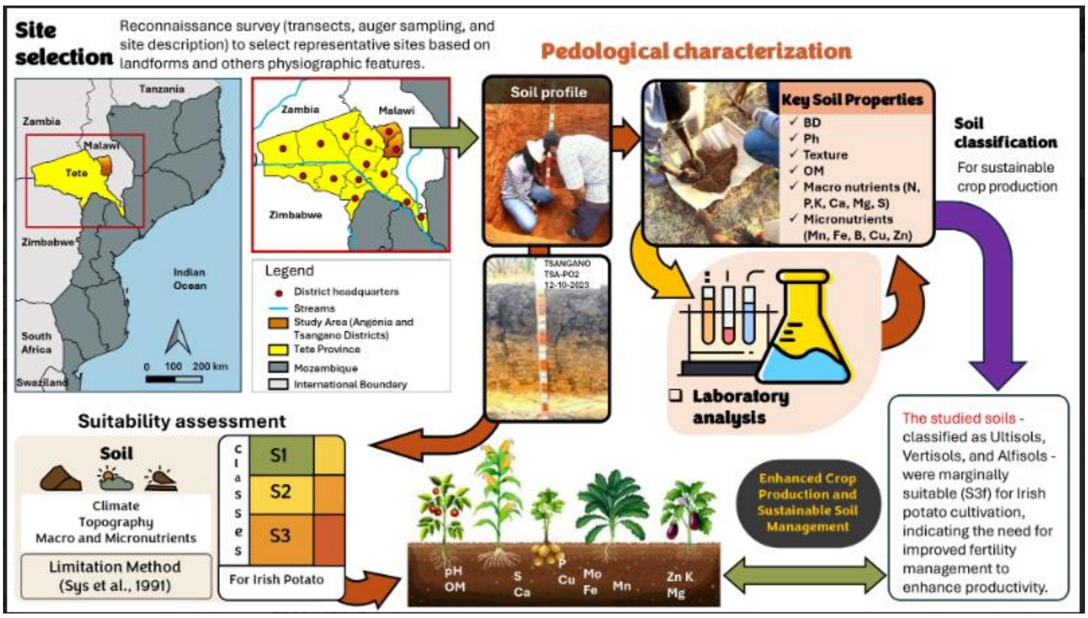

Figure 1 Soil characterization and suitability assessment for Irish potato cultivation (Adapted from Sande et al., 2025)

2.3 Description of irrigation regimes

Irrigation regimes were divided into full irrigation, moderate deficit, and severe deficit. These levels were defined using percentages of field capacity (FC) or crop evapotranspiration (ET). The control group (CK) maintained the soil moisture at 65%~75% of the field capacity (FC) (in the 0-60 cm soil layer). When there is a mild water shortage, the soil moisture content drops to 55%~65% of FC. When there is moderate water shortage, soil moisture drops to 45%~55% of FC (Li et al., 2025). In the research on plastic film mulching and drip irrigation, crops have sufficient water for most of the time, and the amount of water is reduced only during the seedling stage or when tubers are forming. When moderate water deficiency treatment was carried out during the formation and swelling of tubers, the yield decreased by approximately 18.9%, with a loss of 28,633 kg/hm² (Pan et al., 2025).

In an open-field drip irrigation experiment in Chile, the determination of irrigation volume mainly referred to the total effective water volume (TAW), water consumption coefficient (p), and available water volume (RAW). When the RAW consumption reaches 35%, the crops undergo adequate irrigation treatment (T1). Moderate deficiency treatment (with an irrigation volume of 75% of T1, that is, T3) reduced the irrigation water volume throughout the entire growing season by approximately 25%, equivalent to about 80 mm. Compared with full irrigation, the differences in commodity yield and quality under this treatment were not significant, but the water use efficiency increased by approximately 18% (Mora-Sanhueza et al., 2025). More severe deficit treatments, such as 50% and 30% of full irrigation (T4 and T5), caused clear reductions in leaf area, photosynthesis rate, and PSII quantum efficiency during tuber formation and flowering. Final yield and marketable rate were much lower than those under full irrigation and the 75% treatment.

3 Potato Varieties Evaluated

The tested materials included main or widely used potato varieties. They covered different maturity groups and different uses, such as table potatoes and processing potatoes. This helped cover the whole growth period, from early to mid–late maturity, and different market needs. Field comparisons showed that varieties with high yield and a high share of marketable tubers gained more economic benefit when irrigation was improved. For example, in a trial with 21 varieties in eastern India, the yield of ‘Kufri Arun’ reached 35.52 t/ha, and ‘Kufri Pukhraj’ reached 33.54 t/ha. Both varieties had a high share of marketable tubers and high net income. The net income of ‘Kufri Arun’ was 2137.4 USD·ha^{-1}, with a benefit–cost (B:C) ratio of 2.17 (Das et al., 2021). In the Ethiopian highlands, the total yield of ‘Belete’ was 32.8 t/ha, and marketable yield reached 29.1 t/ha. This was much higher than the local farmer variety, which produced only 13.8 t/ha (Tessema et al., 2020).

3.1 Selection criteria for varieties

Variety selection mainly focused on commercial value. Key factors included planting area in the target region or similar environments, fit with market and processing needs, and economic return. In the western highlands of Cameroon, the improved variety ‘Cipira’ produced 7.78 t/ha. This was much higher than the local variety ‘Banso’ (4.0 t/ha) and several European varieties (0.72~3.33 t/ha). ‘Cipira’ also showed lower late blight incidence. For this reason, it was recommended to farmers under both rainfed and supplemental irrigation conditions (Tatah et al., 2023).

The average weight of the tubers of early-maturing varieties is 55.9 g. The average weight of the tubers of the mid-maturing and late-maturing varieties was 85.6 g and 109.6 g respectively. The average weight of the tubers of the late-maturing variety "Rodeo" reaches 128.7 g. The total output of certain late-maturing varieties of commercial potatoes reached 41.69~43.21 t/ha (Yatsenko and Yatsenko, 2025). Under the arid climate conditions of Russia, Bakunov et al. (2025) conducted multi-year experiments on 50 varieties. Some varieties performed very well, with an average yield ranging from 32.0 to 40.9 t/ha. The yields of varieties such as "Krasnoyarsky ranniy", "Alka" and "Vostorg" are relatively stable. The growth rate of early-maturing varieties is relatively fast. The growth of the above-ground parts is particularly obvious 30 to 40 days and 50 to 60 days after emergence. In early varieties, about 52% of yield was seed tubers. In mid- and late-maturing groups, food tubers made up 63% and 60% of yield. This shows that different maturity groups play different roles in the supply chain.

3.2 Morphological and agronomic characteristics of selected varieties

In the 21-variety trial in eastern India, plant height, stem number, leaf area index (LAI), dry matter (DM) accumulation, and crop growth rate (CGR) differed clearly among varieties. 'Kufri Anand' showed higher LAI and DM. 'Kufri Pukhraj' had the highest net photosynthetic rate (NPR) at 60 and 80 d after emergence. 'Kufri Chipsona-4' showed the highest stomatal conductance (SCR) at both stages. 'Kufri Chipsona-3' and 'Kufri Surya' had the highest transpiration rate (TR) at 60 and 80 d (Das et al., 2021). For tuber bulking rate (TBR), 'Kufri Pukhraj' showed the highest TBR before 60 d. After 60 d, TBR increased clearly in 'Kufri Arun' and 'Kufri Surya'. By extending and strengthening the late bulking stage, these mid-maturing varieties achieved higher final yields.

In the research on genotype and irrigation time, when water shortage occurs during the tuber formation period, the relationship between multiple growth indicators and the yield of individual tubers is very close. The taller the plant, the higher the yield tends to be. The same is true of transpiration rate, photosynthetic rate and water use efficiency. These indicators are all significantly positively correlated with tuber yield, and the corresponding correlation coefficients are 0.92, 0.65, 0.95 and 0.88 respectively. But in the mature stage, the situation is different. The greater the total biomass in the aboveground part, the lower the tuber yield. The two are negatively correlated ($r = -0.85$). Under conditions of deficient irrigation, high-yield genotypes are more likely to concentrate dry matter in the tubers rather than for the growth of the above-ground parts (Zhang et al., 2025). In the comparative experiment on the Ethiopian Plateau, the number of tubers per plant of 'Belete' was greater, the average tuber weight was larger, and the proportion of commercial tubers was also higher. The dry matter content and starch content of this variety are both higher than those of local varieties. In terms of tuber morphology, it is mainly composed of medium to large tubers, with a relatively high level of dry matter. Under different water treatment conditions, the influence of tuber size distribution on water use efficiency can be further analyzed by combining the size and composition characteristics of these tubers (Tessema et al., 2020).

4 Experimental Design and Crop Management

4.1 Experimental layout

In New Brunswick, the research lasted for five years and a total of 88 sites were selected. Each field plot was divided into multiple experimental plots, and replicates were set up, generally no less than three replicates, in order to distinguish the effects of soil texture and soil organic matter on crop yield changes (Singh et al., 2025). In Ethiopia and its plateau areas, variety trials used a randomized complete block design. Each test had three replicates. The plot size was about 9~12 m² (Tessema et al., 2020; Asnake et al., 2023). This study can use a similar split-plot randomized block design. Irrigation level is the main plot factor, with full, moderate, and severe deficit irrigation. Varieties are set in subplots. Each treatment has at least three replicates. Plot size is about 15~20 m².

4.2 Crop management practices

The selection of seed potato size is based on previous studies in highland areas. In the highlands of Ethiopia, seed potatoes are classified into small seed potatoes (about 31.5 g), medium seed potatoes (about 57 g) and large seed potatoes (about 77.5 g). Only healthy seed potatoes with good bud eyes will be used. Large seed potatoes can grow taller plants, produce more tubers and have a higher yield (Asnake et al., 2023). The study selected approximately 50~60 g of medium-sized seed potatoes. All plots were applied with the same fertilizers, including 180 kg/ha of NPS and 176 kg/ha of urea, and the field management measures were also the same.

4.3 Irrigation scheduling and application methods

Irrigation timing was set using total available water (TAW), the depletion fraction (p), and readily available water (RAW). When p was 0.35, irrigation began after 35% of RAW in the root zone was used. Soil water was tracked with FDR sensors. In the Hexi Oasis, regulated deficit irrigation (RDI) is used based on the soil moisture content in the 0~60 cm soil layer compared to the field capacity (FC). Irrigation starts when the soil moisture drops below a certain level, like 55% of FC. When it reaches the upper limit, such as 65% FC, irrigation is stopped (Li et al., 2025; Pan et al., 2025). Water use was measured with water meters or by dripper flow rate and irrigation time, then converted to mm or m^3/ha.

5 Yield and Yield Component Measurements

5.1 Total tuber yield

After harvest, border rows and sample rows were removed first. All tubers in the net plot were then dug out and weighed. The weight was converted to fresh tuber yield (t/ha). In a 7-variety test in the central highlands of Ethiopia, the variety Belete had a total yield of 32.8 t/ha, while the local variety Nech Abeba produced only 13.8 t/ha. This shows that, under the same management, yield differences between varieties were more than 2.4 times (Tessema et al., 2020). In a 21-variety trial in eastern India, yields ranged from 21.8 to 35.5 t/ha. The medium-maturing variety Kufri Arun and the early-maturing Kufri Pukhraj both produced more than 33 t/ha (Das et al., 2021). In the present study, total yield of each variety was measured under three irrigation levels. Analysis of variance was used to test the main effect of irrigation and the interaction between variety and irrigation.

5.2 Yield components

Ukrainian studies found that early-maturing varieties typically produce about 8.8 tubers per plant, mid-maturing varieties produce around 7.7, and late-maturing varieties give about 8.9. The average tuber weight is 55.9 g for early-maturing, 85.6 g for mid-maturing, and 109.6 g for late-maturing varieties (Yatsenko and Yatsenko, 2025). When larger seed potatoes were used, the commercial yields of Belete and Gudanie varieties increased to 39.13 and 38.63 t/ha, respectively. In contrast, local varieties planted with smaller seed potatoes produced only 12.12 t/ha (Asnake et al., 2023).

5.3 Water-use efficiency indicators

When irrigation is reduced to 75% of the usual level, water usage during the growing season goes down by about 25%, saving roughly 80mm of water per hectare. This leads to an 18±4% increase in crop water use efficiency (Mora-Sanhueza et al., 2025). In the Hexi Oasis, a combination of plastic film mulching, drip irrigation, and regulated deficit irrigation (RDI) is used. Cutting back on water during tuber formation causes a small yield drop of around 7.16%. However, water productivity goes up by 7.53%, and irrigation efficiency improves by 13.18%. But if water is reduced later in the growing season, the yield decline is bigger, and the improvements in water efficiency are less noticeable (Pan et al., 2025).

6. Results

6.1 Yield response of potato varieties under different irrigation regimes

A study in Chile found that using more water (T2, 130% of T1) led to a much higher yield compared to the low water treatments. The moderate water deficit treatment (75% of T1) still gave a similar yield to full irrigation, even though it used 25% less water. This shows that after a certain point, using more water doesn't always result in a bigger yield (Mora-Sanhueza et al., 2025). In the Hexi Oasis irrigation area, full irrigation at 65%~75% of field capacity (FC) gave the best photosynthesis rate and dry matter accumulation. But when mild deficit irrigation (55-65% FC) was used during the seedling and tuber formation stages, the yield was 42,963.97 kg/ha, which was close to the full irrigation yield, and it saved water too (Li et al., 2025).

6.2 Interaction effects between variety and irrigation regime

The interaction between variety and irrigation often means that different varieties lose yield at different levels under the same reduced irrigation. Based on this, varieties can be grouped as “stable” or “sensitive” to water stress. When water shortage occurs during the tuber formation stage, plant height, transpiration intensity, photosynthetic rate and water use efficiency are all closely related to the yield of individual tubers. The correlation coefficient is between 0.65 and 0.95. At the mature stage, the aboveground biomass shows a significant negative correlation with the tuber yield instead. Researchers screened varieties such as "Challenger", "Sifra" and "Tyson", and believed that they had good drought resistance throughout the growth period (Zhang et al., 2025).

When diseases, high temperatures and drought occurred simultaneously that night, the output of this type of variety dropped significantly. The European varieties grown in Cameroon have a yield of only 0.72~3.33 t/ha. The varieties are relatively sensitive to water shortage and diseases, and have insufficient stress resistance (Tatah et al., 2023).

6.3 Changes in yield components under water stress

In water shortage conditions, crop yields mainly drop for two reasons: fewer tubers are formed, and the individual tubers become lighter. For example, with insufficient water and frequent irrigation, plants may produce more tubers, but they will weigh less. However, if the water shortage is severe, this effect is less noticeable. A reduction in leaf area and weakened photosynthesis result in less dry matter production (Mora-Sanhueza et al., 2025; Pan et al., 2025; Zhang et al., 2025). In Ukraine, a study comparing different varieties showed no major difference in the number of tubers per plant, which ranged from 7.7 to 8.9. However, the tuber weight varied widely (Yatsenko and Yatsenko, 2025). For mid- and late-maturing varieties, when water stress occurs during starch accumulation, the first noticeable change is a decrease in tuber weight, while the number of tubers stays fairly constant.

7 Discussion

7.1 Yield differences among varieties under low water

If there isn't enough water during the tuber formation stage, photosynthesis is closely linked to the final yield, with about a 0.95 correlation. However, during the mature stage, the biomass of the aboveground parts is negatively related to the yield. In conditions with limited water, high-yield, drought-resistant varieties usually have fewer leaves. These plants keep a moderate leaf area, which helps photosynthesis stay stable. This way, more dry matter goes to the tubers instead of the aboveground parts (Zhang et al., 2025). A study in eastern India looked at 21 potato varieties. The mid-maturing high-yield variety "Kufri Arun" and the early-maturing variety "Kufri Pukhraj" both gave high yields, but in different ways. "Kufri Arun" kept a high tuber biomass ratio (TBR) after 60 days of growth, while "Kufri Pukhraj" reached a high TBR in the first 60 days. Mid-maturing varieties are more affected by water shortage later on, while early-maturing varieties are more affected during the early growth stage (Das et al., 2021).

7.2 Meaning for irrigation management in potato farming

Studies from Chile and the Hexi Oasis show similar findings. Reducing irrigation by 20%~25% (for example, using 75% T1 or 55%~65% of field capacity) usually does not affect marketable yield when compared to full irrigation. At the same time, water use efficiency can increase by about 18%-22%, and irrigation water productivity can improve by 7%~13% (Li et al., 2025; Mora-Sanhueza et al., 2025; Pan et al., 2025).

However, when water deficit becomes stronger, or when it happens during very sensitive stages such as tuber initiation and bulking, yield loss increases fast and can reach 18.9%~40%. In practice, light water deficit can be used first at the seedling stage and part of the vegetative stage. For medium- and late-maturing varieties that are sensitive during tuber formation and bulking, water supply should stay close to full irrigation in these stages. For drought-tolerant or early varieties, moderate water reduction can be used in part of the mid stage. In areas with very limited water, using varieties that stay stable under climate change and water fluctuation can further lower risk. Examples include varieties with high adaptability and stable performance such as ‘Alka’ and ‘Vostorg’.

7.3 Comparison with earlier studies

The 75% T1 treatment plan can reduce irrigation water consumption by approximately 25% while maintaining the same output. Mild to moderate underirrigation has little impact on yield. Moderate deficiency irrigation can increase the content of starch, sugar and protein in tubers. Excessive water deficiency or deficiency irrigation at inappropriate times (such as during the tuber formation and expansion period) can lead to decreased yield and quality issues (Zhang et al., 2025). If some varieties show significant yield losses after a 20%~30% reduction in irrigation water usage, it may be because the water deficiency occurs precisely during their main tuber swelling period (Mora-Sanhueza et al., 2025).

Acknowledgments

We would like to express our gratitude to the two anonymous peer researchers for their constructive suggestions on our manuscript.

Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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