



Water uptake efficiency in hibiscus and butterfly pea as representations of branched tap and fibrous root systems

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Abstract

Aims: This study investigates water absorption capabilities in two plant species—Hibiscus (*Hibiscus rosa-sinensis*) with a branched tap root system and Butterfly Pea (*Clitoria ternatea*) with a fibrous root system—to assess how root architecture influences water uptake.

Study Design: An experiment was set up with controlled conditions, as mentioned in the methodology, $n = 3$.

Duration of the Study: 72 Hours.

Methodology: Three plants of each species were placed in identical pots and submerged in jars containing 2.5 liters of water each, with water levels reaching half the height of the pots.

Understanding the efficiency of water uptake in different root systems is crucial for optimizing irrigation practices, especially in water-limited environments. The main hypothesis proposed was that the tap root system of Hibiscus would absorb water more efficiently than the fibrous root system of Butterfly Pea.

Results: After 72 hours, the water level in the Hibiscus jars was noticeably lower than that in the Butterfly Pea jars, indicating greater water uptake by the Hibiscus plants. These results were consistent across all three tests.

Conclusion: Under the given conditions, the branched tap root system of Hibiscus is more effective in water absorption than the fibrous root system of Butterfly Pea.

Keywords: Water uptake efficiency, branched tap roots, fibrous roots, root hydraulics, rate of water absorption by plants

Introduction

Water is essential for plant growth, impacting critical processes such as nutrient transport, photosynthesis, and cellular metabolism (McIntyre, G. I., 1987) ^[1]. The increasing unpredictability of global climate, including frequent droughts, heightens the importance of understanding how plants absorb and utilize water efficiently (Parmesan & Hanley, 2015) ^[2]. Efficient water uptake plays a crucial role in crop productivity and ecological balance, especially in arid or water-limited environments (Ali & Talukder, 2008) ^[3]. Given the significant challenges posed by water scarcity, optimizing plant water use is vital for agriculture, particularly in drought-prone regions (Preite, L., *et al.*, 2023) ^[4].

Root systems are key to a plant's ability to access water from the soil. There are two primary types of root systems: tap and fibrous. Tap-rooted species, such as *Hibiscus rosa-sinensis*, have a central, deep-growing root that can reach water reserves deep in the soil (Yamada, T., *et al.*, 2005) ^[5]. Hibiscus, having branched tap root system, can cover vast regions in the soil, providing easier access to water. In contrast, fibrous-rooted species like *Clitoria ternatea* (Butterfly Pea) feature a network of shallow, fine roots that are more efficient at absorbing moisture from the upper soil layers (Helmisaari, H. S., 2000) ^[6]. The distinct characteristics of these root systems may suggest different efficiencies in water uptake, but direct comparisons under controlled conditions remain limited.

Branched tap roots and fibrous roots differ in structure and function. A tap root, originating from the radicle, grows thicker and deeper, forming a central, primary root with smaller lateral roots (Hankin, S., *et al.*, 2019) ^[7]. This structure helps anchor the plant and access deep water and nutrients. In contrast, fibrous roots consist of numerous thin,

equally sized roots that emerge from the base of the stem. They spread horizontally, creating a dense network of roots near the surface, ideal for absorbing water and nutrients from the topsoil (Diggle, A. J., 1988) ^[8]. Tap roots are typical of dicots, while fibrous roots are common in monocots (Pagès, L., 2016) ^[9]. Each system adapts to specific environmental conditions.

In agricultural practices, fibrous-rooted **crops** such as rice, maize, and wheat are cultivated extensively in regions with fertile, well-irrigated soils, benefiting from their rapid growth and efficiency in nutrient absorption (Fageria, N. K., *et al.*, 2008) ^[10]. On the other hand, tap-rooted plants like alfalfa and deep-rooted trees are vital in regions with dry climates, where their ability to reach deeper water sources and store nutrients is essential for sustainability (Dordas, C., 2008) ^[11].

Previous studies have suggested that tap roots are advantageous in accessing deeper soil moisture, particularly in drought conditions (Yamada, T., *et al.*, 2005) ^[5]. On the other hand, fibrous roots may be more efficient in exploiting surface water or in areas with high rainfall and shallow soil moisture (Helmisaari, H. S., *et al.*, 2000) ^[6]. However, the direct comparison of water uptake rates between these two root types remains an underexplored area in plant physiology. Understanding this concept can certainly contribute to the development of modern agriculture.

Hence, the central research question is: How does root morphology (tap vs. fibrous) influence the rate of water absorption in these plants? The hypothesis is that Hibiscus, with its deeper tap root system, will absorb more water over a fixed period than Butterfly Pea, as branched tap roots are more effective in accessing water from deeper soil layers (Yamada, T., *et al.*, 2005; Helmisaari, H. S., 2000) ^[5, 6].

In the experiment, three healthy plants of each species, of similar sizes, were placed in pots with identical soil and submerged halfway in water-filled jars. Over a 72-hour period, the amount of water absorbed by each plant was measured by the reduction in water level in the jars. The results showed that Hibiscus plants consistently absorbed more water than Butterfly Pea plants in both trials, supporting the hypothesis that branched tap-rooted species are more efficient in water absorption (Yamada, T., *et al.*, 2005) [5].

These findings suggest that tap-rooted species like Hibiscus may have an advantage in environments where water is stored deeper in the soil. Butterfly Pea, with its fibrous root system, may be better suited to environments with more readily available surface water. Understanding these differences can help in selecting appropriate species for water-limited agricultural systems and inform future research on optimizing plant water use in different ecological contexts (Patakas, A., *et al.*, 2005) [12].

The observed trend aligns with known botanical principles of root functionality, offering a solid foundation for future research with expanded sample sizes, longer time durations, or alternative environmental variables (Wang & Jackson, 2023) [13].

In conclusion, the results confirm the hypothesis that root system morphology significantly influences water uptake, with branched tap roots in Hibiscus enabling more efficient water absorption than the fibrous roots of Butterfly Pea under controlled conditions.

Materials and Methods

Two species were chosen based on the primary characteristic under investigation: root system morphology. *Hibiscus rosa-sinensis*, a dicotyledonous plant known for its prominent branched tap root system, was selected to represent branched tap-rooted plants (Pagès, L., 2014) [14]. *Clitoria ternatea*, commonly known as Butterfly Pea, which has a fibrous root system typical of many legumes, was chosen as the fibrous-rooted counterpart (Tomlinson, P. B., 1970) [15]. Three healthy, similarly sized plants (approximately 25–30 cm tall) from each species were used in this experiment, allowing for all three trials to examine consistency across different individuals of the same species.

All plants were sourced from a certified local nursery and were of comparable maturity. Each plant was carefully transplanted into a 15 cm diameter, 13 cm high plastic pot with seven pre-drilled holes at the base (Foreverup 17CM Clear Orchid Pots, Cat. No. B0CMC3741T). These drainage holes allowed for passive water absorption through capillary action when the base of the pot was submerged in water. All pots were filled with equal volumes of garden soil, supplemented with approximately 15% coco peat by volume to enhance moisture retention and ensure even root development (Hussain & Farooq, 2023) [16].

To evaluate water uptake efficiency, each potted plant was placed into a transparent plastic jar with a capacity of 3 liters (Bormioli Fido Clip Jar, Cat. No. 8004360008043). Each jar was filled with 2.5 liters of distilled water (Winstons ARION Distilled Water, Cat. No. 401835149), with the water level adjusted to reach halfway up the height of each pot (~6.5 cm). This ensured that water was absorbed exclusively through the holes at the bottom of the pot, without meeting the plant above the soil. Care was taken to

prevent water from entering the topsoil directly, ensuring that the only water accessible to the roots was that absorbed from the base. The point of contact between the pot and the jar was sealed using clay and tape, to ensure that the water does not evaporate (see Figure 1, Figure 2).



Fig 1: Initial Water Levels in Both Plant Jars. Image showing the equal starting water levels (2.5 L) in jars containing *Hibiscus rosa-sinensis* and *Clitoria ternatea* ($n=3$). Plants were placed in identical pots with 7 drainage holes and set in jars with 2.5 L of water each



Fig 2: Water Levels in Plant Jars After Three Days. Image showing reduced water levels after 72 hours, with Hibiscus jars retaining 2.21 L and *Clitoria ternatea* jars ($n=3$) retaining 2.42 L. Plants were maintained under identical conditions without watering for three days

The experiment was conducted in a stable indoor environment with ambient temperatures of approximately 25°C and consistent natural lighting. Plants were not moved once placed, and no additional watering, misting, or environmental interference occurred over the course of the study. All equipment was sanitized prior to use to prevent cross-contamination.

Initial water levels were measured precisely using a graduated measuring cylinder (Borosil, Cat. No. 3021029) and verified by volume markings on each jar. After a fixed period of 72 hours (3 days), the remaining water volume in each jar was measured again under the same conditions. The net difference in water volume indicated the total amount of water absorbed by the plant over the three-day period.

This procedure was carried out thrice using different individuals from each species to confirm consistency and reduce the chance of individual variation influencing results. All measurements were recorded manually, and no plant showed signs of wilting or visible stress during the observation period. The observed water reduction served as the primary data for assessing root system water uptake efficiency.

Results and Discussion

The rationale for conducting this experiment stemmed from the critical role root architecture plays in water absorption efficiency, especially in agricultural systems facing water scarcity (Zhang, Y., *et al.*, 2024) [17]. Different root systems—specifically tap and fibrous roots—are believed to absorb water differently due to their structural adaptations. Tap roots, such as those seen in *Hibiscus rosa-sinensis*, typically penetrate deeper into the soil, potentially accessing water from lower horizons. In contrast, fibrous roots, like those of *Clitoria ternatea* (Butterfly Pea), form a dense network closer to the soil surface. This study sought to determine whether these anatomical differences translate into measurable differences in water uptake when both plants are exposed to identical environmental and water conditions (Chavarria & dos Santos, 2012) [18].

To evaluate this, three trials were conducted using three different healthy, similarly sized plants of each species. All six plants were potted in identical plastic pots (15 cm diameter) with seven pre-drilled drainage holes, (sourced from Foreverup 17CM Clear Orchid Pots, Cat. No. B0CMC3741T). Each pot was then placed inside a clear plastic jar filled with 2.5 liters of water (up to half the pot's height). No external watering was provided over a 72-hour observation period. The setup was maintained indoors at a constant room temperature ($25 \pm 2^\circ\text{C}$) with natural light, ensuring uniform environmental conditions. The only variable between the setups was the plant species, thus isolating root structure as the independent variable (Kuhn & Brannock, 1977) [19].

Water levels in the jars were measured at the beginning and end of the experiment. In both trials, the Hibiscus plants demonstrated a greater reduction in water volume compared to the Butterfly Pea plants. Specifically, the first Hibiscus plant absorbed approximately 0.39 liters of water, leaving 2.21 liters behind, while the paired Butterfly Pea plant absorbed 0.15 liters, with 2.35 liters remaining. A similar pattern was observed in the second and third trials, where Hibiscus again absorbed more water than its Butterfly Pea counterpart by about 200–250 mL. This consistent difference in water absorption strongly supports the initial hypothesis.

The initial and final water volumes for each plant (Table 1) demonstrates a consistent pattern: tap-rooted Hibiscus plants absorbed more water than fibrous-rooted Butterfly Pea plants.

Table 1: Water volume in jars containing Hibiscus and Butterfly Pea plants over a three-day period. Values represent approximate measurements of water (in litres) remaining in the jars at each time point

Day	Water in Jar with Butterfly Pea (L)	Water in Jar with Hibiscus (L)
0 (Initial)	2.5 L	2.5 L
3	2.35 L	2.21 L

The results also highlight that the advantage of the Hibiscus tap root system persists even in relatively shallow setups, suggesting that the lateral branches of tap roots may contribute significantly to absorption, not just their vertical depth. This observation expands the relevance of tap root efficiency to environments such as potted systems, where deep penetration is limited (Burkhart, B., 2006) [20].

The results of this study support the hypothesis that branched tap-rooted species, such as *Hibiscus rosa-sinensis*, are more efficient in water uptake compared to fibrous-rooted species, like *Clitoria ternatea* (Butterfly Pea). Across three trials with different plant samples, the Hibiscus plants consistently absorbed more water than the Butterfly Pea plants. In all three experiments, the Hibiscus plants absorbed approximately 200–250 mL more water over a three-day period, as indicated by the reduced water levels in their jars. This confirms that the branched tap root system of *Hibiscus* provides an advantage in water absorption, supporting our hypothesis that deeper root structures are more effective at accessing water from deeper soil layers (Yamada, T., *et al.*, 2005) [6].

The rationale behind this experiment was to assess whether root morphology influences water uptake under controlled conditions. Tap roots can access water stored deeper in the soil, while fibrous roots, which are widespread but shallow, absorb moisture from upper soil layers (Zhang, D., *et al.*, 2019) [21]. By keeping the water level constant and limiting the soil volume available to both species, we simulated an environment where tap-rooted plants could access water deeper in the substrate, providing a framework for testing root architecture's effect on water uptake (Lynch, J., 1995) [2].

Several factors could have influenced the results. Although the experiment included three replicates per species, a larger sample size would improve statistical power and reduce variability (MacKay, R. J., *et al.*, 1997) [23]. Future studies could examine a wider range of species, especially those with variations in root architecture, to improve generalizability (Nibau, C., *et al.*, 2008) [24]. Moreover, controlling environmental factors, such as humidity or temperature fluctuations, could reduce experimental variation (Parker, M. W., 1946; Potvin, C., 2020) [25, 26].

A limitation of the study is the measurement method used to track water uptake. Although the reduction in water volume in the jars served as the primary indicator, more precise techniques—such as using soil moisture sensors, gravimetric measurements, or isotopic tracing—could provide more accurate data on water absorption, independent of evaporation (Babaeian, E., *et al.*, 2019) [27]. To further improve measurement precision, using sealed

environments or weighing the plants before and after the experiment could minimize sources of error (Hawkins, B. K., 2001)^[28].

Transpiration could influence water absorption, as plants with larger leaf surface areas or more stomatal openings may transpire more water (Kramer, P. J., 1937)^[29]. Preventive measures, such as ensuring same humidity for both the plants, and not watering the plants, so that both plants conserve water, have been taken to control the effect of transpiration. However, future experiments could control transpiration by measuring leaf surface area or conducting transpiration assays (Yoo, C. Y., *et al.*, 2009)^[30].

Despite these limitations, the results provide insights into how root structure affects water use efficiency. Tap-rooted species like *Hibiscus* are better suited for environments where water is deeper in the soil profile, while fibrous-rooted species like *Butterfly Pea* might be more effective in environments with shallow moisture (Fitter, A. H., 1987)^[31]. This finding is relevant for agricultural practices in regions that face water scarcity or variable rainfall (Grayson, M., 2013)^[32].

While this experiment shows a correlation between root architecture and water uptake, it does not establish causation. The results of this study should therefore be interpreted as indicative of a trend rather than a definitive cause-and-effect relationship. Future studies that explore these additional factors are needed to further our understanding of root water uptake efficiency (Jackson, R. B., 2000)^[33].

Several questions remain for future exploration. How does root system efficiency vary under drought or other stress conditions. Additionally, it would be valuable to study how root systems adapt to varying water availability over time (Calleja-Cabrera, J., *et al.*, 2020)^[34]. Root plasticity, the ability of plants to modify their root architecture in response to water stress, could influence long-term water uptake efficiency (Karlova, R., *et al.*, 2021)^[35], however, this does not apply to this study as it was conducted for a span of three days. Experiments conducted for longer periods of time can deal with the effect of root plasticity.

In conclusion, the results of this study support the hypothesis that tap-rooted plants, like *Hibiscus rosa-sinensis*, are more efficient at absorbing water compared to fibrous-rooted plants, such as *Clitoria ternatea*. Tap roots provide an advantage in accessing water stored deeper in the soil, which could be beneficial in drought-prone or water-limited environments. However, further research should consider a broader range of species, environmental factors, and long-term plant performance to fully understand the implications of root system morphology on water uptake efficiency (Wang & Smith, 2004)^[36].

Conclusion

The experiment supports the hypothesis that the branched tap root system of *Hibiscus* is more effective in water absorption than the fibrous root system of *Butterfly Pea* under the given conditions. The deeper and more centralized structure of the tap root likely allowed *Hibiscus* plants to access water more efficiently from the lower levels of the pot. This finding highlights the importance of root architecture in determining water uptake efficiency. A common example of the use of a tap rooted plant, *Solanum trilobatum*, is in dentistry. *Solanum trilobatum* has got certain antibacterial properties, which helps against dental

pathogens (Ganesan, Kumar, *et al.*, 2024)^[37]. Understanding such differences is vital for selecting suitable plant species in water-scarce environments and can inform better irrigation practices for sustainable agriculture and horticulture.

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