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WUE AND ITS RELEVANCE IN WATER PRODUCTIVITY - INTRINSIC AND WHOLE PLANT WUE APPROACHES TO MEASURE WUE - GRAVIMETRY, INSTANTANEOUS AND CARBON ISOTOPE DISCRIMINATION

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Water Use Efficiency (WUE) is a critical concept in both agriculture and environmental management, particularly as global water resources become increasingly scarce. WUE refers to the efficiency with which water is utilized by plants to produce biomass. It is defined as the ratio of biomass produced to the amount of water used, either through transpiration or water applied in agricultural practices. The importance of WUE extends beyond simple water conservation; it directly impacts crop productivity, economic output, and sustainability. Improving WUE can lead to higher yields with less water in agriculture, making it a key strategy in regions facing water shortages or drought conditions. Various approaches, including optimized irrigation techniques, crop selection, and soil management, enhance WUE. Additionally, understanding intrinsic and whole-plant WUE provides insights into plant responses to water stress, helping develop more resilient agricultural systems that thrive in changing climatic conditions.

Water use efficiency

It is a physiological trait that describes the efficiency of crop plants in using available water for carbon fixation. It is defined as biomass production per unit of water consumption.

Agronomically

Amount of biomass produced per unit of water applied.

Physiologically

Amount of biomass produced per unit amount of water transpired.

Water use efficiency

While the term “water use efficiency” is used to describe the effectiveness with which the water supplied in the field is used for plant growth or evapotranspiration, the term

Water productivity

Water productivity refers to the amount of economic output or value generated per unit of water used. It's a measure of how efficiently water is used to produce goods and services. The concept is often used to assess the sustainability of water use in various sectors, such as agriculture, industry, and municipalities.

Its relevance in water productivity

Water Use Efficiency (WUE) refers to the ratio of the amount of water used for a specific purpose (e.g., crop growth, industrial process) to the total amount of water withdrawn or diverted from a source (e.g., river, reservoir, aquifer). It measures how effectively water is used to achieve a desired outcome.

WUE is highly relevant to water productivity because it directly impacts the economic output or value generated per unit of water used.

Improving WUE

1. Reduce water losses and waste
2. Increase crop yields or industrial output per unit of water used
3. Enhance water productivity and efficiency
4. Support sustainable water management practices
   - Genetics: Some crop varieties are naturally more water-efficient.
   - Breeding programs often focus on developing crops with higher WUE.
   - Agricultural Practices: Optimized irrigation, soil management, and precision agriculture can enhance WUE, thereby improving water productivity.

In agriculture, WUE can be improved through techniques like:

- Drip irrigation
- Mulching
- Crop selection and breeding
- Soil conservation

Applications in Agriculture Drought Resistance

In drought-prone areas, crops with high WUE can maintain productivity with less water, which is crucial for food security.

Irrigation Efficiency

Efficient irrigation systems that match water supply to crop demand can improve WUE and overall water productivity.

Sustainable Agriculture

By focusing on WUE, farmers can produce more food with less water, helping to conserve water resources and adapt to changing climatic conditions.

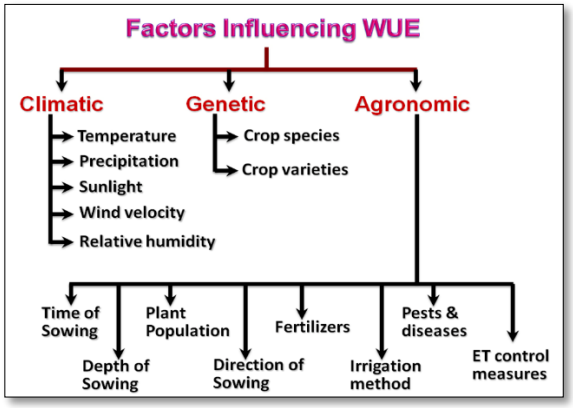
Agronomic measure	Physiological measures
Crop selection	Drought tolerance
Soil conservation	Water uptake efficiency
Irrigation management	Transpiration efficiency
Fertilizer management	Hormone regulation
Crop rotation	Breeding for WUE

Agronomical measures focus on external factors (management practices, crop selection) to optimize water use.

Physiological measures focus on internal plant processes (drought tolerance, water uptake, transpiration efficiency) to improve WUE.- Agronomical measures are often more readily implementable, while physiological measures require more research and development.

Factors influencing water use efficiency:

- Climate
- Genetic
- Agronomic



Intrinsic& whole plant WUE

Intrinsic Water-Use Efficiency (iWUE)

Definition: Intrinsic WUE refers to the ratio of carbon assimilation (photosynthesis) to stomatal conductance (the rate at which CO_2 enters and water vapor exits the stomata) under controlled environmental conditions.

Focus: iWUE reflects the efficiency with which a plant uses water at the leaf level, independent of external water availability. It is particularly useful in understanding how plants balance carbon gain with water loss under varying environmental conditions.

Whole-Plant Water-Use Efficiency (wp WUE)

Definition: Whole-plant WUE is a broader measure that considers the entire plant's water use relative to the biomass produced over a growing period.

Formula: It is often calculated as the ratio of the total biomass (or yield) produced by the plant to the total water consumed.

Focus: wpWUE integrates water use over the entire plant's life cycle and considers all water losses, making it more reflective of the plant's overall water economy. It is particularly important for understanding agricultural productivity and crop water management.

Intrinsic WUE	Whole-plant WUE
Leaf-level measurement	The entire plant
Focuses on short-term physiological responses	While WPWUE reflects long-term growth and productivity.
Often used in physiological studies	More relevant for agriculture and ecological studies

Approaches to measure WUE

- Gravimetry,
- Instantaneous &
- Carbon isotope discrimination.

Gravimetric Method

This method involves measuring the amount of water consumed by a plant over a certain period and relating it to the biomass or yield produced.

Measurement of WUE by gravimetric approach involves the measurement of dry matter accumulated over a specific period of time and the total water transpired by the plant during the same period.

Principle of the Gravimetric Method

The gravimetric method involves weighing the amount of water lost (evapotranspiration) by a plant during its growth and correlating this with the plant's biomass gain. By tracking the water supplied and the changes in soil water content, can determine the total water used by the plant.

- Plants are typically grown in containers or pots filled with soil or another growth medium. The containers are placed on scales to monitor changes in weight over time. Water is applied to the containers, and the exact amount is recorded. The water may be applied manually or through an automated irrigation system.
- The container (with the plant) is weighed regularly (e.g., daily or weekly) to determine the amount of water lost due to evapotranspiration (the combination of evaporation from the soil surface and transpiration through the plant).
- The difference in weight between successive measurements indicates the amount of water lost, which is attributed to the plant's water use.
- At the end of the experiment, the plant is harvested, and its biomass (dry weight) is measured.
- The dry weight is obtained by drying the plant tissue at a constant temperature until no further weight loss occurs.
- WUE = Biomass (Dry Weight) / Water Used

Advantages of the Gravimetric Method

- Provides accurate measurement of water use at the whole-plant level.
- The method is straight forward, requiring basic equipment like scales, containers, and a drying oven.
- Direct Measurement: It directly measures the amount of water used by the plant, rather than relying on indirect estimations.

Limitations of the Gravimetric Method

- Labor-Intensive: Frequent weighing and careful control of water input are required, making the method labour-intensive.
- The method is often limited to controlled environments (e.g., greenhouse or growth chambers), and container size can affect root growth and water uptake patterns.
- This method is less practical for large-scale field studies but works well for small experiments and controlled conditions.

Instantaneous method for measuring water-use efficiency

The instantaneous method for measuring water-use efficiency (WUE) is typically performed using gas exchange measurements, which allow for the rapid assessment of WUE at the leaf level.

This method calculates WUE based on the rates of photosynthesis and transpiration in real-time

Principle of the Instantaneous Method

The instantaneous WUE is calculated as the ratio of the rate of carbon assimilation (photosynthesis) to the rate of transpiration. This reflects how efficiently a plant uses water to fix carbon dioxide into sugars at a specific moment in time.

WUE=A/EInstantaneous

Where:

A = Rate of photosynthesis (µmol CO_2 m^2 s^{-1})

E = Rate of transpiration (mmol H_2O m^2 s^{-1})

A portable infrared gas analyser (IRGA)

Advantages of the Instantaneous Method

- ✓ This method provides rapid results, allowing for real-time assessment of WUE under varying environmental conditions.
- ✓ It captures the plant's response to changes in environmental factors (e.g., light, humidity) instantly.
- ✓ Allows for detailed physiological studies, including the effects of stress, such as drought or high temperatures, on WUE.

Limitations

- ✓ The instantaneous WUE reflects only the current conditions and may not represent long-term water-use efficiency.
- ✓ Requires specialized equipment (e.g., IRGA or gas exchange systems), which can be costly and require training to use effectively.
- ✓ This method typically measures WUE at the leaf level, which may not fully represent whole-plant or field-scale WUE.

Carbon isotope discrimination

- ➢ The carbon isotope discrimination method is an indirect but highly effective way to measure water-use efficiency (WUE) in plants, particularly over long periods and across different environments.
- ➢ This method relies on the analysis of stable carbon isotopes in plant tissues, which are influenced by the plant's photosynthetic processes and stomatal behaviour.

Principle of Carbon Isotope Discrimination

- ➢ Carbon exists naturally as two stable isotopes: $12C$ (the most common form) and $13C$ (a heavier, less common form). During photosynthesis, plants preferentially take up $12C$ over $13C$
- ➢ The degree of discrimination against $13C$ (notated as Δ) is influenced by the plant's stomatal conductance and the intercellular CO_2 concentration (ci), both of which are linked to water-use efficiency.

- A lower stomatal conductance (indicating higher WUE) results in less discrimination against $13C$, meaning the plant tissue will have a higher ratio of $13C$ to $12C$

Isotope Analysis

The carbon isotope ratio ($\delta^{13}C$) is measured using mass spectrometry. The ratio is expressed relative to a standard

$$\delta^{13}C = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1\right) \times 1000$$

where R is the ratio of $13C/12C$ in the sample and the standard.

The std for carbon is a limestone called Fossil Belemnite from Pee-Dee Formation – PDB

Calculation of Carbon Isotope Discrimination (Δ)

Carbon isotope discrimination (Δ) is calculated based on the $\delta^{13}C$ values and reflects the plant's discrimination against $13C$ during photosynthesis. It is related to the internal CO_2 concentration (ci) and thus to WUE.

Estimating WUE

- A lower Δ (less discrimination against $13C$ indicates higher WUE.
- There is an inverse relationship between Δ and WUE, meaning that as Δ decreases, WUE increases.

Advantages

- Unlike instantaneous methods, the carbon isotope discrimination method integrates WUE over the period during which the tissue was formed, providing a long-term average of WUE
- Field Applicability: This method is particularly valuable for field studies, as it does not require specialized equipment at the time of measurement—just the collection of plant tissue samples.
- The method is less sensitive to short-term environmental fluctuations and can provide a more stable measure of WUE.

Limitations

- Indirect Measurement: While carbon isotope discrimination is related to WUE, it is an indirect measure and requires careful interpretation.
- Specialized Analysis: Requires access to mass spectrometry and expertise in isotope analysis, which can be costly and time-consuming.
- Between Δ and WUE can vary between species, requiring species-specific calibration.

Conclusion

Optimizing water-use efficiency and water productivity is central to the future of agriculture and water management. As water becomes an increasingly limited resource, the ability to produce more with less water will be vital. Through a combination of technological innovation, improved management practices, and genetic advancements, we can ensure that water resources are used more sustainably, supporting both agricultural productivity and environmental conservation.

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