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Understanding Virtual Water and Its Calculation in Agricultural Products

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Virtual water refers to the amount of water embedded in the production of goods and services, particularly agricultural products. It's the water used in the entire process of producing a product, from growing crops or raising animals to manufacturing and processing. This includes not just the direct water used for irrigation or watering livestock, but also the indirect water used in producing inputs like fertilizers and energy, and the water consumed in processing and transportation. Virtual water is composed of three forms of water: green water, grey water, and blue water.

- **Green Water:** Water stored in the soil that is available for plants through evapotranspiration.
- **Blue water:** Water found in surface water bodies (rivers, lakes, reservoirs) and underground aquifers.
- **Grey water:** Water that has been used and contains impurities, often from domestic or industrial activities, but is not highly polluted.

For example, it takes a significant amount of water to produce a kilogram of grain, meat, or even a cup of coffee—water that is used throughout all stages of production, even if it's not immediately visible.

Emergence of the Concept of virtual water

The concept of virtual water was introduced by British geographer **John Anthony Allan** in the 1993 to highlight the hidden flow of water in trade.

Rationale behind virtual water trade:

- In regions with water scarcity, importing water-intensive products can be a strategy to conserve local water resources.
- It revealed the interconnection between global trade and water resources, emphasizing that water scarcity could be mitigated through trade policies.

Drivers of virtual water trade:

- Globalization and increasing international trade.
- Rising awareness of water scarcity and the need for efficient water resource management.
- Climate change and its impact on water availability.

Calculation of virtual water content

The concept of virtual water content refers to the specific water demand, which is the ratio of crop water requirement to crop productivity. When the crop water requirement is high or crop productivity is low, the specific water demand increases. Crop water requirement is influenced by crop evapotranspiration, which includes both evaporation from the soil surface and transpiration from the plant surface. These processes are also affected by geophysical properties. Evaporation is influenced by geological factors and weather conditions, while transpiration is impacted by soil properties. To generalize these parameters, we first calculate the reference evapotranspiration, and then, based on this value, we determine the crop evapotranspiration by adjusting it with a crop-specific factor.

Specific water demand: The virtual water content is also called as specific water demand which is the ration of crop water requirement (m^3/ha) to crop productivity (m^3/tonn).

Crop water requirement: The calculation of virtual water content begins with determining the crop water requirement, which is the amount of water needed to replace the water lost by a crop through evapotranspiration under optimal growth conditions, without any water shortages (Allen *et al*., 1998). The crop water requirement consists of three types of water: green water, blue water, and grey water.

Crop water requirement = $10*\sum_{t=field\ prepration}^{Crop\ growing\ period} ETcrop$

Where $ET_{crop} = K_c*ET_0$

Reference evapotranspiration (ET0) is a crucial concept in understanding and estimating the water requirements of crops. It refers to the evapotranspiration rate of a hypothetical grass reference crop that is grown under conditions where water is abundant and not a limiting factor. This hypothetical reference crop is used as a standard for measuring the potential evapotranspiration rate in any given location. By selecting a site with an ample water supply for this calculation, the goal is to ensure that water availability does not restrict the evapotranspiration process. In doing so, ET0 is designed to solely represent the evaporative potential of the atmosphere, reflecting the atmospheric conditions that influence evapotranspiration at a specific time and place. It’s important to note that ET0 does not account for variations in crop types, soil properties, or any other local conditions that might affect water use. Essentially, ET0 isolates the atmospheric conditions, such as temperature, humidity, wind speed, and solar radiation, as the sole contributors to evapotranspiration. The value of ET0 can thus be interpreted as the "evaporative power" of the atmosphere for a given time and location, providing a baseline against which the water needs of different crops can be compared.

In the context of India, reference evapotranspiration is calculated using localized climate data sourced from the Indian Meteorological Organization (IMD). This allows for a more accurate estimation of ET0 tailored to India’s diverse climatic conditions. The IMD’s database provides the necessary information on temperature, humidity, solar radiation, and wind speed, which are critical in determining the potential evapotranspiration rates specific to different regions of the country. The crop coefficient (Kc) is a key factor in translating ET0 into crop-specific water requirements. Kc is a multiplicative factor that adjusts the reference evapotranspiration to account for the actual water needs of a particular crop. It serves as the link between the evapotranspiration rate of the reference crop (ET0) and the evapotranspiration of the actual crop (ETc) being studied. The Kc value varies depending on several factors, including the type of crop, the prevailing climate, and the stage of crop growth. The crop coefficient is not constant throughout the growing season. It changes as the crop progresses through its different growth stages. During the early stages of growth, the crop's canopy might not be fully developed, and the crop coefficient will typically be lower. As the crop matures and its ground cover increases, so does the crop coefficient, reflecting the growing water demand as the crop reaches its full vegetative potential. For instance, during the flowering or fruiting stages, the crop may require more water due to higher transpiration rates driven by the increased leaf area and crop height. Consequently, the value of Kc rises to reflect these increased water requirements.

Furthermore, several factors can influence the crop coefficient, including soil type, crop variety, local climate conditions, and agricultural practices. In areas where irrigation is applied, the water application rate and the efficiency of the irrigation system can also play a role in determining the effective crop coefficient. Additionally, different crops exhibit distinct water use patterns, and therefore, their Kc values will vary not only by growth stage but also by crop species.

The total growing period is typically divided into four distinct growth stages: the initial stage, the crop development stage, the mid-season stage, and the late season stage (Allen *et al*., 1998). The initial stage refers to the period from planting until the crop reaches about 10% ground cover. The crop development stage spans from 10% ground cover to when the crop achieves effective full cover. The mid-season stage occurs from the point of effective full cover until the crop begins to mature. The late season stage is the final phase, starting when the crop begins to mature and lasting until harvest.

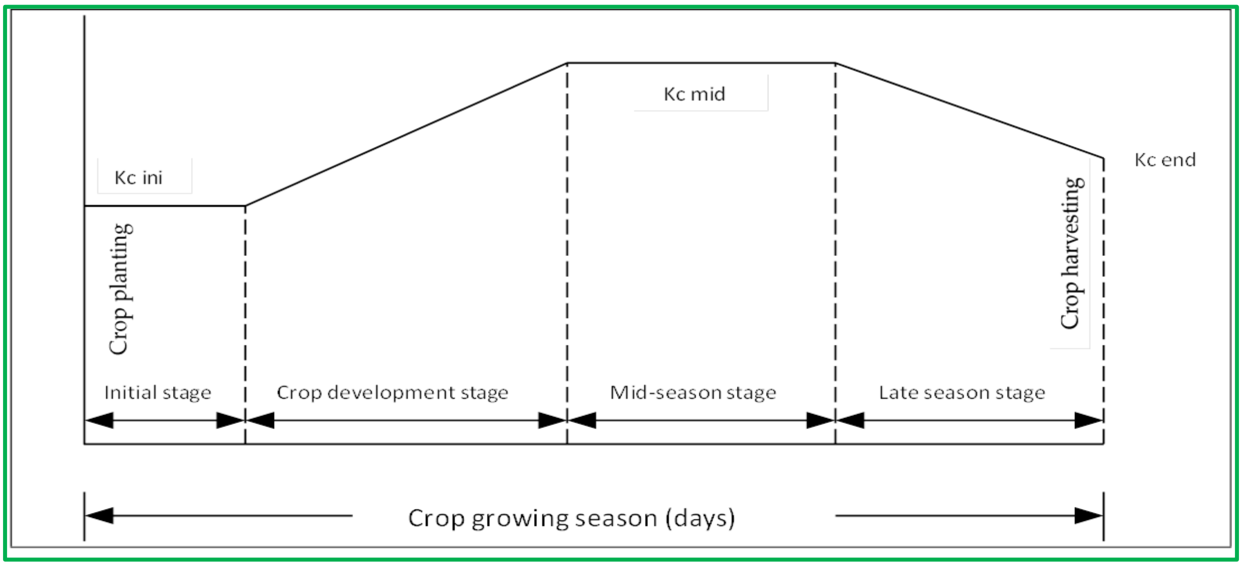

Figure: Different crop growing stages and development of K_c (Source: Kampman, 2007).

Green crop water use: Green crop water use refers to the volume of water from total rainfall that is actually utilized by the crop field to meet its evapotranspiration needs, measured in cubic meters per hectare (m3/ha). This is particularly calculated under rainfed conditions throughout the crop's growing period. The concept of green water emphasizes the importance of rainfall in fulfilling the water demand for crop growth, as opposed to water derived from irrigation or other sources. For estimating green water, the effective rainfall, which constitutes a significant portion of the virtual water used by crops, is a crucial component. The FAO's Cropwat model provides a detailed method for calculating this effective rainfall component, also referred to as green virtual water, as well as the monthly irrigation requirement for the crop. The model considers various factors such as local rainfall, soil type, and the net depth of irrigation needed to meet the crop's water requirements. In essence, the effective rainfall represents the portion of rainfall that is actually available to the crop, after accounting for losses due to evaporation, runoff, and other non-productive uses. Therefore, the FAO's Cropwat model is essential in estimating how much of the total rainfall is effectively available for crop growth, and how it contributes to the crop's water needs over the growing period.

When using the Cropwat model to calculate effective rainfall, it factors in both soil properties and irrigation requirements. The soil type plays a crucial role in determining how much of the rainfall is retained in the soil and available for plant uptake. For instance, sandy soils may drain water more quickly than clay soils, meaning less effective rainfall is available in sandy soil conditions. By conditioning the effective rainfall based on these soil characteristics, the model provides a more accurate representation of how rainfall contributes to meeting the crop's evapotranspiration demands. In addition to the rainfall component, the Cropwat model also calculates crop evapotranspiration (ETc) values for each of the four growth stages of the crop. These stages are the initial stage, crop development, mid-season, and late season. Throughout these stages, the water needs of the crop change due to variations in factors such as crop size, leaf area, and transpiration rates. The Cropwat model incorporates these changes by considering crop parameters, such as the crop type and its growth stage, alongside the climatic conditions and soil properties. This allows the model to estimate the crop's daily water use (evapotranspiration) during each growth stage, and to assess how much of this water demand can be met through effective rainfall and how much additional irrigation might be required. By combining all these factors—effective rainfall, soil characteristics, crop parameters, and evapotranspiration values—FAO's Cropwat model offers a comprehensive framework for understanding and managing the green water component in agriculture. It enables better planning of water usage, helps in the optimal design of irrigation systems, and supports sustainable agricultural practices by promoting efficient use of natural water resources. Additionally, it provides a foundation for assessing the role of virtual water in the overall water footprint of crop production, aiding in the management of water resources on both local and global scales.

Blue crop water requirement: Blue crop water requirement refers to the amount of water used for irrigation throughout the entire crop growing period. Unlike green water, which is derived from rainfall, blue water is the water applied through irrigation to supplement the crop's water needs when rainfall is insufficient to meet evapotranspiration demands. Blue water is a critical component in regions where rainfall alone cannot provide enough water for crops, and irrigation becomes essential to ensure optimal crop growth. This water requirement is typically measured in terms of the volume of irrigation water needed per hectare (m3/ha), and it can vary depending on several factors, including crop type, climate, soil characteristics, and the efficiency of the irrigation system. The calculation of blue water takes into account the crop's evapotranspiration needs during each stage of growth and identifies how much water needs to be supplied via irrigation to bridge the gap between rainfall and crop water demand. The method used to calculate blue water is similar to that of green water, with the primary distinction being that it focuses on irrigation rather than natural rainfall. It involves determining the total crop water requirement and subtracting the effective rainfall (green water) that contributes to meeting this demand. The remaining water requirement is then classified as blue water, representing the volume of water that must be supplied through irrigation to ensure the crop receives adequate water throughout the growing season. This calculation considers factors such as the crop coefficient (Kc), which adjusts the reference evapotranspiration (ET0) to account for the specific water needs of the crop at different growth stages. By accurately calculating blue water, farmers and water resource managers can make informed decisions about irrigation practices, ensuring that crops receive sufficient water while minimizing waste and promoting more sustainable water management.

Crop water use$_{\mathrm{blue}}$ = $10*\sum_{t=field\ prepration}^{crop\ growing\ period} ETc$

Gray water requirement: Gray water requirement refers to the amount of water necessary to dilute and flush out pollutants like nitrates from the soil surface, which often result from the use of nitrogen-based fertilizers in farming. High nitrate concentrations in the soil can be harmful to the environment and human health, as they have the potential to contaminate groundwater and degrade water quality. The purpose of calculating gray water is to ensure that these harmful substances are adequately diluted and removed from the soil, preventing them from leaching into water bodies. Although this water does not directly contribute to crop growth, it plays a vital role in mitigating the environmental impact of agricultural activities, particularly in areas where chemical fertilizer use is widespread. The quantity of gray water needed depends on several factors, including soil type, the extent of contamination, and the amount of nitrogen fertilizer applied. Different soils have varying abilities to hold or filter out contaminants, which mean the gray water requirement can differ significantly from one field to another. For example, sandy soils, with their lower water retention capacity, may require more water to flush out nitrate pollutants compared to clay soils, which are better at holding nutrients. Furthermore, the amount of nitrogen fertilizer applied directly influences the level of nitrate contamination, with higher fertilizer use typically leading to more nitrates in the soil, thus increasing the gray water requirement. Given the variability in gray water needs, it is challenging to calculate on an individual basis without detailed information on soil properties, fertilizer usage, and other local factors.

However, this requirement is often estimated at the regional or state level, assuming uniform soil conditions across the area. By analyzing the total amount of nutrients applied in a given region and considering typical soil characteristics, an average gray water requirement for agricultural fields can be derived. While this approach helps create general water management strategies, it may not fully account for the specific needs of every field.

References

1. Allan, J. A. (1998). Virtual water: a strategic resource. *Ground water*, *36*(4), 545-547.
2. Amini, A., Othman, K., Abassi, F., & Booij, M. J. (2024). Determining virtual water, physical and economic indices to optimize agricultural water consumption in three different climates. *International Journal of Environmental Science and Technology*, 1-14.
3. Hoekstra, A. Y., & Hung, P. Q. (2003, December). Virtual water trade. In *Proceedings of the international expert meeting on virtual water trade* (Vol. 12, pp. 1-244).
4. Kampman, D.A., 2007. Water footprint of India: a study on water use in relation to the consumption of agricultural goods in the Indian states. Masters Thesis, University of Twente, Enschede, the Netherlands.