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Water Use Efficiency (WUE): Key trait for Water Budgeting

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SUMMARY

Limited availability of water resources is the major obstacle in sustainable agricultural production. Hence fore, to get maximum yield within minimum use of irrigation, it is necessary define the water requirement of the crop. This water requirement may vary with the growth stage, soil, climate and so on. Optimizing this requirement of water to the crop can facilitates efficient irrigation.

INTRODUCTION

India is blessed with varied climatic conditions; some regions receive ample rainfall however some regions are prone drought like conditions. This climatic conditions mark a significant effect on the agriculture of respective zones. Areas which receive less rainfall are mainly dependent on ground water. In such regions, ground water is the key source of irrigation for crop (Gandhi and Namboodiri, 2009; Suhag 2019). But at present this ground water table is lowered to threshold level due to frequent and countless use of ground water (Ritter *et al*.,2002). Along with this reason, many external and internal factors are responsible for lowering the ground water pool (Brunke and Gonser, 1997; Kløve *et al*., 2011). This lowering of ground water creates great challenge to farmers and agricultural researchers as well. Agricultural researchers are implementing plenty of ideas to get maximum production with minimum use of ground water. Hence to get success in above mentioned idea, it is necessary to understand the concept of water use efficiency of crop and according to that crop should irrigated. To decide appropriate need of irrigation to particular crop, it is advisable to study its water use efficiency first. This serves the purpose of water saving. Water use efficiency is an amount of carbon assimilated as biomass or grain produced per unit of water used by the crop (Jerry *et al*. 2019) or it is ratio of water used in plant metabolism to water lost by the plant through transpiration (https://en.wikipedia.org/wiki/Water-use_efficiency). In other words, WUE intensify capability to forecast how climate change may affect carbon and water budgets (Hu *et al*., 2008).

Impact of WUE

WUE can help to predict the potential yield of crop (Mo *et al*., 2005). The increasing water use efficiency is positively increasing the yield to the amount of nitrogen fertilizer application (Gregory, 2004). Soil water plays an important role in nitrogen uptake (Walsh *et al*. 2012). If nitrogenous fertilisers applied more than requirement of crop then WUE may increase the risk of leaching the N and accumulation of N at root zone (Zotarelli *et al*., 2008).

Measurement of water use efficiency related concept

Water Use Efficiency (WUE)

$$\mathbf{WUE} = \frac{\mathbf{Y}}{\mathbf{ET}}$$

Where,

Y- Economic yield in kg ha^{-1}, biomass yield in kg ha^{-1} and energy yield (MJ ha^{-1}) (Chai et al. 2014)

ET- Evapotranspiration (mm)

Evapotranspiration (ET)

ET can be calculate by given formula

$$\mathbf{ET} = Pr + Ir + \Delta S + Wg - D - R$$

Where,

Pr – Precipitation

Ir – Irrigation water

ΔS - Change in soil water content over the measured soil depth during the growth period
Wg - Water used by crops through capillary rise from groundwater
D - Deep drainage below the root zone
R – Surface runoff (all in millimetres mm)

Water Productivity (WP)

$$WP = \frac{\text{Agricultural benefit}}{\text{Water use}}$$

Water Use Efficiency of major field crops grown in India

Crop	WUE range (kg m^{-3})	Average WUE (kg m^{-3})
• Rice	0.30-0.54	0.45
• Wheat	0.58-2.25	1.24
• Maize (Rabi)	0.49-1.63	0.91
• Sorghum	0.56-1.43	0.88
• Pearl millet	0.41-0.70	0.54
• Chickpea	0.40-4.02-	1.60
• Green Gram	0.37-2.43	.44
• Pigeon pea	0.27-0.72	0.46
• Groundnut	0.20-1.11	0.50
• Sunflower	0.16-0.93	0.59
• Soybean	0.35-01.04	0.60
• Sugarcane	3.25-7.83	4.68
• Cotton	0.17-0.40	0.26

(Source: Singh, 2010, Yadav *et al*., 2000)

Plant Physiology and Water Use Efficiency

WUE directly affects the physiological processes of plants (Hsiao and Acevedo, 1975). Basically, the plant is a hydraulic channel between the soil and atmosphere. Canopy and root architecture, organ morphology, anatomy, and aquaporin activity greatly influenced by a plant's water uptake capacity, water transport efficiency and water loss as well. WUE not only affects the structure of plant but also affect its biochemistry and histology (Pandey *et al*., 2017).

Water use efficiency in C_3 and C_4 plants

Jerry *et al*. 2011 reported the relation of water use efficiency between C_4 and C_3 plants. In C_4 biochemical pathway, in which the first products of photosynthesis are C_4 carboxylic acids (CA) and specific bundle sheath anatomy of leaves permit higher rates of photosynthesis as compared to the C_3 biochemical pathway. As C_4 plants often, but not always, have lower stomatal conductance, the TE of C_4 species is significantly greater than that of C_3 species when directly compared in the same environment. However, C_4 species are often grown in warmer and drier environments than C_3 species, so that water use efficiency may be similar because of the greater vapour pressure deficits in the warmer and drier environments or seasons. The highest values of TE are found in those plants that fix carbon via the carboxylic acid metabolism (CAM) pathway, whereby the plant opens its stomata and takes up CO_2 in the dark when vapor pressure deficits and water loss are low. CAM plants store the carbon as the C_4 malate in mesophyll cells and use sunlight to convert the malate to carbohydrates behind closed stomata (Ting, 1985).

While the CAM biochemical pathway is very efficient in terms of water productivity, dry matter production is very low and is generally found in specialized plants living in extremely dry environments. However, a crop species that has the CAM pathway is pineapple (*Ananas comosus*), but as some species can switch between CAM and C_3 pathways depending on water supply (Dodd *et al*. 2002), it is likely that pineapple uses the C_3 pathway when irrigated for fruit production.

Plant canopy

Plants with high density canopy shows maximum relative humidity and minimum temperature. The rate of transpiration is less due to light reflection because of less penetration of light. Canopy affects light interception and reflectance; it ultimately reduces photosynthesis. But vertically arranged leaves allow greater light during day due to angle of sun. (Yunasa *et al*. 1993). Leaf level WUE has distinguishing pattern depending on crassulacean acid metabolism, C_4 and C_3 carboxylation pathway. C_4 plant higher inherent WUE than C_3 (Taylor *et al*. 2010)

CO_2 Concentration

Increasing of carbon dioxide CO_2 is positively related to water use efficiency, but in C_3 plants increasing CO_2 level that affect the photorespiration. However, in C_4 plant photorespiration has limiting factor there is no additional impact of increasing of CO_2 level under normal water condition (Jerry et al. 2019). In drought stress high CO_2 levels is beneficial due to partial stomata closing thus falling transpiration, and the capacity of C_4 plants to integrate carbon even when stomata are closed (Lopes *et al*. 2011).

Genes that effect WUE

The collaborating systems of traits and biochemical development that regulate TE indicate that TE is under the control of a whole suite of genes TE may be under the control of a single gene that findings suggested by Masle *et al*. (2005). A number of genes identified that influenced on water use efficiency. These genes mainly responsible for signalling and water transport (Bramley *et al*. 2013).

Climate change

Cropping system is relating with climate with changes in phenology, growth, yield, and water use (Hatfield *et al*., 2011). The climate change impacted on radiation use efficiency and water use efficiency, these parameters are directly related to plant growth. Ozone negatively related with water use efficiency because of the effect on leaf senescence and maintenance of leaf area of the alfalfa canopy. This proves that climate change influences could ascend from many different parameters that would affect WUE (Jerry at al. 2011).

Trait effects on WUE

Edwards et al. 2012 stated in his study the many traits affected on water management (eg. biomass, height, number of stems etc) has been associated with other. Conversely, the rank order of genotypes reversed across treatments; those genotypes with the lowest WUE in well-watered conditions had the highest water use efficiency (WUE) under drought Feldman et al. 2018 observed very close association between crop growth and water use efficiency in *Setaria* spp. As of latest advances in high-throughput phenotyping and quantitative genetics to identify the genetic loci associated with plant size, water use, and WUE in an interspecific RIL population of the model Setaria spp. From the findings it is suggested that the major genetic components associated with plant size, water use, and WUE exhibit pleiotropic performance and that the magnitude of their allelic effects is dependent upon the environment and developmental stage. Plant parameter that exhibited the lead to increasing water use efficiency was kernels per plant. The resilience of genetic material to stress, e.g., temperature or water, will provide the newer genetic material with greater water use efficiency (Jerry *et al*. 2019).

Types of Water Use Efficiency

Photosynthetic water use efficiency (instantaneous water use efficiency) - It is ratio of rate carbon assimilation to the rate of transpiration called as photosynthetic water use efficiency (Mir 2012, Wikipedia).

Water use efficiency of productivity (integrated water use efficiency) - It is defined as the ratio of biomass produced to rate of transpiration (Mir 2012, Wikipedia).

Factors affecting WUE of the crop

- Climate
- Type of Crop

- Water table
- Ground Slope
- Intensity of Irrigation
- Conveyance Losses
  - a. Type of soil
  - b. Subsoil water
  - c. Age of canal
  - d. Position of FSL w.r.t to NSL
  - e. Amount of Silt carried by canal
  - f. Wetted perimeter
- Method of Application of water
- Method of Ploughing
- Crop Period
- Base Period
- Delta of a Crop

(https://www.aboutcivil.org/factors-affecting-crop-water-requirement.html)

CONCLUSION

Defining crop specific WUE can help to mitigate the intensified problems of water scarcity. This also facilitates the efficient application of irrigation which always leads to higher yield per unit area. WUE can be improved by adopting various cultural practices like use of micro irrigation, mulching, application PBRs.

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