AgriCos e-Newsletter
ISSN: 2582-7049
Open Access Multidisciplinary Monthly Online Magazine
Volume: 03 Issue:04 April 2022 Article No: 04

Exploiting Water Use Efficiency in an Era of Climate Change

Srikanth G. A.
Assistant Professor, Department of Plant Physiology, Sampoorna International Institute of Agricultural Science and Horticultural Technology, Belekere, Channapatna, Karnataka

SUMMARY

Climate Change is defined as statistically significant variation in either mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The major cause to climate change as been ascribed to the increasing levels of green house gases like CO_2. This changing scenario has got a pronounced impact on agriculture and availability of water for human requirement due to the variations in the temporal and spacial distribution of rain fall.

INTRODUCTION

Water is highly essential to plant growth and development and it constitutes more than 80% of the most of plant cells and tissues in which there is active metabolism (CSIRO, 2008). Available water for irrigation to agricultural purposes is depleting year by year due to increased industrialization and urbanization. Under these conditions, water needs to be conserved and utilized efficiently. Especially under water limited situations, crop productivity is determined by how efficiently water is utilized. Among the several physiological traits, WUE is one of the important trait, which can be explored to develop new genotypes, tolerant to situation.

Role of water in Plants:

Water acts as solvent, plants can absorb nutrients when these nutrients are dissolved in water. And it forms over 90% of the plant body by green or fresh weight basis. Water is used for transpiration carrier of nutrients from the soil to green plant tissues. Plants can synthesis food through photosynthesis only in the presence of water in their system. (Fraiture *et al.*, 2010). Out of the world's allocatable water resource, 80% is currently consumed by irrigated agriculture. But projected population growth will require more of the available water resources (another two billion people within 2-3 decades). This expanded population also needs to be fed & clothed. With population growth and rising affluence, the need for food and thus agricultural water for irrigation is increasing. At the same time the quantity of water with a sufficient quality is declining. There is also an increasing demand to shift more of the water used in agriculture to higher-value urban and industrial uses. So strategies should be developed for maximizing the productions with the efficient use of available water.

Water Use Efficiency

WUE can be defined as the accumulation of assimilation products (photosynthesis)/amount of water used (transpiration), which reflects the energy conversion efficiency per unit of water used in the plant. (Zhang *et al.*, 2003)

Water use efficiency at different levels

- Single leaf level
- Single plant level
- Field level

Single leaf level:

Leaf water use efficiency (WUEl) or transpiration efficiency (TEl) is photosynthesis rate/transpiration rate of specific leaf of the plant.

In single leaf level, WUE is the ratio of carbon assimilation (A) to transpiration rate (T) and is expressed as:

$$WUE = A/T$$

$$A = \frac{\Delta CO_2}{\Sigma r} = \frac{(Ca\text{-}Ci)}{\sum r_a + \sum r_s + \sum r_m} \quad X\ 0.64$$

$$T = \frac{\Delta e}{\Sigma r} = \frac{(ei\text{-}ea)}{\sum r_a + \sum r_s + \sum r_m} \quad X\ 1.64$$

Where,
A/T= Instantaneous water-use efficiency of leaf gas exchange
Ca and Ci = CO_2 concentration in ambient air and leaf intercellular spaces respectively
ea and ei= water vapor concentration in ambient air and leaf intercellular spaces respectively

Water use efficiency for the whole plant (WUEp) is the weight of biomass or economic weight /amount of water used.

Factors Affecting WUE

- Plant factor
- Environmental factor

Plant factors:

- Stomatal character
- Leaf Movement
- Root system

Stomatal character: Stomata are the "gatekeepers" responsible for all gaseous diffusion, and they adjust to both internal and external environmental stimuli governing CO_2 uptake and water loss. The pathway for CO_2 uptake from the bulk atmosphere to the site of fixation is determined by a series of diffusional resistances, which start with the layer of air immediately surrounding the leaf the boundary layer (ra). Stomatal pores provide a major resistance to flux from the atmosphere to the substomatal cavity within the leaf (stomatal resistance) (rs). Further resistance is encountered by CO_2 across the aqueous and lipid boundaries into the mesophyll cell and chloroplasts mesophyll resistance (rm). Although the cumulative area of stomatal pores only represents a small fraction of the leaf surface, typically less than 3%, 98% of all CO_2 taken up and water lost passes through these pores.

Leaf movements: Leaf is the substrate where both assimilation and transpiration takes place to the maximum. Transpiration normally shows a positive relationship with increasing irradiance. Hence leaf movement and surface reflectance pattern affect energy load on the leaf. Leaf pubescence helps in controlling the leaf temperature and water balance. (Molden, D., 2007)

Root system: The distribution of roots, its density can influence water use by crops. Thus the rate of root growth & their spread can affect WUE, particularly during early stages of crop growth. Root growth has direct relation with transpiration and it was established in several crops. Plants with deeper root growth are able to extract more soil moisture from deeper soil profiles and cause higher transpiration (Tron *et al*., 2015).

Environmental factors:

Vapour pressure deficit (VPD), Light, Temperature, CO_2 concentration, Moisture stress, Influence of Nutrients.

WUE and Climate Change

Raising CO_2 influences WUE mainly through its impact on photosynthesis ans transpiration.

Physiological effects of elevated CO_2

- Modification of stomatal development.
- Modifications in stomatal behavior.
- Effects on the leaf
- Effects on photosynthesis
- Changes in rooting pattern
- Decrease in crop duration.

Positive effects of CO_2 on crop production

Elevated carbon dioxide increases the productivity and water use efficiency of nearly all plants. Higher levels of atmospheric CO_2 improve, and sometimes fully compensate for, the negative influences of various environmental stresses on plant growth. (Alcamo. J., 2007)

Significance of achieving higher WUE

Most yield improvements have been achieved by increasing carbon assimilation and decreasing the transpirational components through management and breeding.

Strategies for enhancing WUE

- Agronomical approaches
- Physiological approaches

Case Studies:

Carbonic anhydrases, EPF_2 and a novel protease- CRSP mediate CO_2 control of stomatal development (Cawas *et al.*, 2015)

The continuing rise in atmospheric CO_2 levels is suppressing the development of stomatal pores in plant leaves on a global scale. This, combined with the increasing scarcity of water for agriculture, can significantly affect plant carbon assimilation and water-use efficiency. Julian Schroeder and colleagues investigate the genes and mechanisms through which CO_2 controls development of the stomatal pores that plants use to regulate gas exchange in leaves. At high CO_2 levels, extracellular signalling and carbonic anhydrase regulate a novel protease called CRSP and the pro-peptide EPF_2; this in turn was found to represses stomatal development.

Elevated CO_2 increases tree-level intrinsic water use efficiency: insights from carbon and oxygen isotope analyses in tree rings across three forest FACE site.

(Battipaglia *et al.*, 2013)

WUE was analyzed at three Free Air CO_2 Enrichment (FACE, POP-EUROFACE, in Italy; Duke FACE in North Carolina and ORNL in Tennessee, USA) sites, stable isotope discrimination technique was used to assess the changes in water-use efficiency, Across all the sites, elevated CO_2 increased ^{13}C-derived water-use efficiency on an average by 73% for Liquidambar styraciflua, 77% for Pinus taeda and 75% for Populus sp.

The *ERECTA* gene regulates plant transpiration efficiency in *Arabidopsis*

(Masle *et al.*, 2005)

Carbon isotopic discrimination of plant matter was a reliable and sensitive marker related to variation in transpiration efficiency, the isolation of a gene that regulates transpiration efficiency. *ERECTA*, a putative leucine rich repeat receptor like kinase (LRRRLK) and its effects on inflorescence development is a major contributor to a locus for on *Arabidopsis* chromosome 2. And mechanisms include, but are not limited to, effects on stomatal density, epidermal cell expansion, mesophyll cell proliferation and cell-cell contact.

Improvement of water use efficiency in rice by expression of *HARDY*, an *Arabidopsis* drought tolerance gene

(Karaba, *et al.*, 2007)

Expression of the Arabidopsis HARDY (HRD) gene in rice improves water use efficiency, the ratio of biomass produced to the water used, by enhancing photosynthetic assimilation and reducing transpiration. These drought-tolerant, low-water-consuming rice plants exhibit increased shoot biomass under well irrigated conditions and an adaptive increase in root biomass under drought stress. The application of a gene identified from the model plant Arabidopsis for the improvement of water use efficiency coincident with drought resistance in the crop plant rice.

Genetic diversity and evolution of crop water use efficiency

Over the last few decades, evidence has accumulated that there is substantial variability for WUE within species, suggesting that WUE is a factor that can be improved through selection. (Turral, *et al.*, 2010)

Techniques to quantify WUE

- Gas exchange
- Gravimetry
- Carbon isotopic discrimination (IRMS)

WUE modifications under elevated CO_2 enrichment- FACE system

Free-air carbon dioxide enrichment (FACE) allows experiments with controlled atmospheric concentrations of carbon dioxide to be conducted in the field

Strategies for Enhancing Water-use Efficiency in Agriculture

- Improving water holding capacity
- Intensification of irrigated area development and water management schemes.
- Improving water resources
- Cultivation of less water intensive and more remunerative crops (Crop Diversification).

Government initiatives

- Micro Irrigation system
- MGNREGA schemes.

CONCLUSIONS

Climate change is real and the most important factor contributing by increasing CO_2 concentration. This consequence will undoubtedly lead to limited availability of natural resources water. The only way out will be producing more dry matter with less water by improving water use efficiency. The current practices followed are agronomic practices which helps in increasing agricultural production. But to get sustainable outcome, we need to identify the real player mediating CO_2 controlled plant responses along with genetic and physiological factors. Exploitation of these factors with an integrated approach of different disciplines will help us to identify and develop crop plants which will enable us to face the future.

REFERENCES

Alcamo, J., Dronin, N., Endejan, M., Golubev, G., and Kirilenko, A. 2007. A new assessment of climate change impacts on food production shortfalls and water availability in Russia. *Global Environmental Change* 17: 429–444.

Battipaglia, G., Jaeggi, M., Saurer, M., Siegwolf, R. W., and Cotrufo, M. F. 2008. Climatic sensitivity of Δ O^{18} in the wood and cellulose of tree rings: results from a mixed stand of Acer *pseudoplatanus* L. and *Fagus sylvatica* L. Palaeogeography Palaeoclimatology Palaeoecology 261: 193–202.

Bondeau, A., Smith, P., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze-Campen, H., Müller, C., Reichstein, M., and Smith, B., 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biol*. 13: 679–706.

Condon, A. G., Richards, R.A., Rebetzke, G. J., and Farquhar, G. D., 2002. Improving intrinsic water-use efficiency and crop yield. Crop Science, 42**:**122–131.

Cawas, B., Majid, E., Ghassemian, M., Jeffrey, C., Scott C., and Hong, H., 2014. Carbonic anhydrases, *EPF2* and a novel protease mediate CO_2 control of stomatal development *Nature*. 11: 513-7517

CSIRO, 2008. WaterAvailability in the Murray–Darling Basin: Areport from CSIRO to the Australian Government. CSIRO, Australia. http://www.csiro.au/files/files/po0n.pdf.

Karaba, A., Dixit, S., Greco, R., Aharoni, A., Kurniawan, R., Martinez, N, M., Krishnan, A., Udaykumar M., and Andy, P., 2007. Improvement of water use efficiency in rice by expression of *HARDY*, and *Arabidopsis* drought and salt tolerance gene. Proc *Natl Acad Sci*, 104(39): 15270–15275.

Turral, H., Svendsen, M., and Faures, J. M., 2010. Investing in irrigation: reviewing the past and looking to the future. Agricultural Water Management 97: 551–560.

Fraiture, C., and Wichelns, D., 2010. Satisfying future water demands for agriculture. Agricultural Water Management, Comprehensive Assessment of Water Management in Agriculture 97 (4), 502–511.

Masle, J., Scott, R., Graham, D., and Farquhar., 2005. The *ERECTA* gene regulates plant transpiration *Arabidopsis Nature* 436: 866-870.

Molden, D., 2007. Water responses to urbanization. Paddy and Water Environment (Special Issue Water Transfers) 5: 207–209

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., and Kijne, J., 2010. Improving agricultural water productivity: between optimism and caution. Agricultural Water Management, Comprehensive Assessment of Water Management in Agriculture 97: 528-535.

Tron, S., Laio, F., and Ridolfi, L., 2015. Plant water uptake strategies to cope with stochastic rainfall. Adv. Water Resource, *Ecological Modelling* 312: 200–210.

Zhang, J. H., Ye, Y. X., Wang, Z. Q., Zhu, Q. S., and Liu, L. J., 2003. Involvement of abscisic acid and ethylene in the responses of rice grains to water stress during filling. Plant, Cell & Environment 27:1055–1064.