Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(5): 1044-1048
Received: 19-06-2020
Accepted: 24-08-2020

Shafeeqa T
Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

D Vijayalakshmi
Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Corresponding Author:
Shafeeqa T
Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Physiological and biotechnological approach to improve water use efficiency in rice (*Oryza sativa* L.): Review

Shafeeqa T and D Vijayalakshmi

DOI: https://doi.org/10.22271/phyto.2020.v9.i5o.12365

Abstract
Rice is the widely cultivated cereal crop in the world. But low water use efficiency of rice (*Oryza sativa* L.) led rice cultivation more water expensive. Due to the climate change, drought and high temperature are the major environmental stress experienced by the plants. In this situation to sustain the yield of rice under limited water consumption is the major concern. Therefore physiological, biotechnological and agronomical approaches are adopted to improve water use efficiency (WUE) of rice. This review focused more about physiological and biotechnological approach to improve water use efficiency of rice.

Keywords: Rice (*Oryza sativa* L.), drought, water use efficiency, biotechnology

Introduction
World population mainly depend on rice as their staple food source. Even though rice is widely adapted cereal crop, its production and productivity is affected by extreme climatic condition. Drought, flood, and land degradation are some of the impact of climate change. Increase of world population added the scarcity of water and land resources. Reports revealed that prediction had been made about the rise in global temperature from 2.4-4.3 ºC, this will be leading to the water scarcity and drought (IPCC 2007) [17]. According to IPCC fifth assessment report warming was recorded 1.5 ºC due to human activity as compared to preindustrial revolution. The increment was around 0.2 ºC per decade (Allen *et al*., 2018) [2]. In some study showed that 50% of the rice yield is reduced due to drought. Therefore improvement of water use efficiency is the one of the strategy that can be used to tackle this situation.
In plants 90% of the water lose through transpiration (Morrison *et al*., 2008) [23] so that reducing transpiration without compromising CO_2 uptake is the major concern. Efficiency of water improved through agricultural practices and genetic improvement are widely studied. Landraces harbored many genes responsible for stress tolerance so that it can be used as candidate gene identification especially for improving water use efficiency. Genetic manipulation mainly focused on genes responsible for stomatal density, ABA signaling and root character through breeding and biotechnological tools like genetic transformation.

Water use efficiency
Water use efficiency is the ratio of biomass or grain yield to the water supplied or evapotranspiration which expressed as Kgm^{-3} water (Sinclair *et al*., 1984) [27].

$$\text{WUE} = \frac{\text{Biomass or grain yield}}{\text{Evapotranspiration}}$$

Flexas, (2016) [12] studied genetic improvement of water use efficiency in C_3 plants and generated equation for intrinsic water use efficiency, it is the ratio of assimilation to stomatal conductance.

$$\text{WUEi} = \frac{\text{Assimilation(intrincic)}}{\text{Stomatal conductance}}$$

Water productivity is another term which also used instead of water use efficiency in many studies. Water productivity is the ratio of agriculture benefit to the water use, the unit is same as that of water use efficiency, which give the holistic water use efficiency of a cultivation (Kijre *et al*., 2003) [20]. One component of water use efficiency is the agricultural product which measured in terms of yield (Kg, mg, t), Energy equalent (Kcal) or income ($).

Evapotranspiration is another component of water use efficiency which can be measured by using equation

$$ET = P + I + G \pm Q - AS$$

Where, P-Precipitation, I- Irrigation, G-net ground water flow, Q-Run on or off ∆S change in soil water content (Allen *et al*., 1998) [1]. In crop plants, C_3 plants like rice, shows lower water use efficiency than C_4 plants like sugar cane and maize. Crassulacean acid metabolism (CAM) plants shows higher water use efficiency than C_4. Irrigation and N_2 fertilizer application increases water use efficiency at certain level, after that it decreases which experimented by Gajri *et al*., (1993) [13] in wheat with varying levels of water and nitrogen fertilizer. Some studies revealed that aquaporin also involve in water use efficiency of rice its inadequate expression leads to limited water use efficiency (Nada and Abogadalla, 2014) [24]. Rice cultivation require large amount of water especially low land rice so that its water use efficiency very low. Many method can be adopted to improve water use efficiency of rice such as wet seeding, mulching, genetic transformation, plant breeding methods and aerobic rice are some of them.

Carbon isotope discrimination

Extent of carbon isotope discrimination in leaves can be correlated with water use efficiency of the crop. The relationship between water use efficiency and $^{13}C/^{12}C$ ratio experimented in a study conducted by Winter *et al*., (2004) [29] using C_3 and CAM plants (Fig.1). In a study, 28 rice cultivars including Indica, Japonica and AUS types were analyzed for carbon discrimination (∆) using the equation ∆=Ra/Rp-1,[where Ra-Isotopic ratio of atmospheric CO_2 Rp- Isotopic ratio of In plant CO_2] which is negatively correlated with WUE (Farquhar and Richards 1984, Wright *et al*., 1988) [9, 30]. Result showed that carbon isotope discrimination and Water use efficiency correlated in Japonica and Aus types but not in Indica group (Dingkuhn *et al*., 1991) [7]. Another study revealed that double haploid and recombinant imbred lines generated from IR64 X Azucena showed genetic variation in the carbon isotope discrimination which is contributed by genetic variation in the carbon metabolism and genetic variation in the stomatal conductance (This *et al*., 2010) [28].

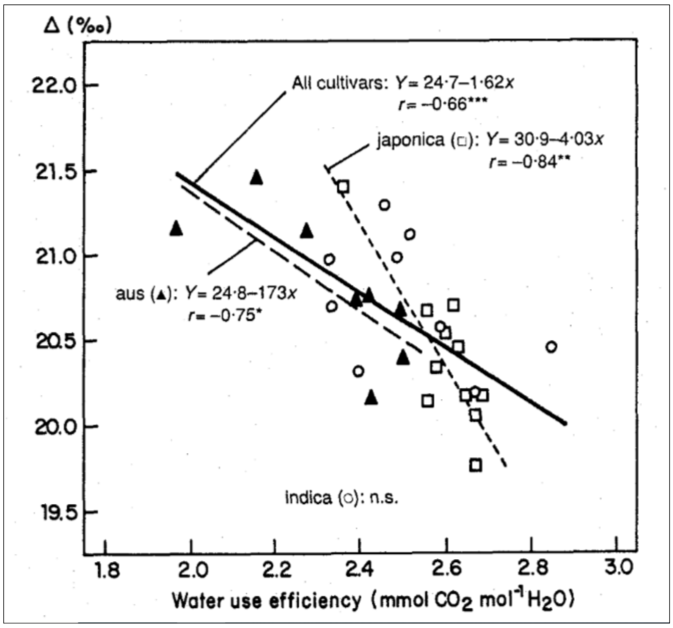

Fig 1: Correlation graph between WUE and ∆ (This *et al*., 2010) [28].

Methods to improve water use efficiency

Water use efficiency of rice can be improved through various methods such as cultural, biotechnological, breeding and physiological approaches. Many studies were conducted under these approaches and results showed improvement in water use efficiency of rice

A. Breeding and Molecular approaches

1. Genetic transformation

Arabidopsis drought and salt tolerant gene HARDY introgressed to rice genome to improve water use efficiency (WUE) in rice (*Oryza sativa* var. Japonica). The rice cultivar Nipponbare was used for the study, results showed that there did not have significant difference in germination, growth and yield but the transformed plants showed increase in leaf canopy (Fig 2) with more number of tillers and significant increase in number of bundle sheath cell (Fig 3). HRD gene plays a role in stomatal conductance as it reduced the stomatal conductance led to increase in water use efficiency (Karaba *et al*., 2007) [18]. A multifunctional protein target of Rapamycin (TOR) present in all eukaryotic organism. In a study TOR gene from Arabidopsis thaliana introgressed in to widely cultivated indica rice variety. The over expression of AtTOR gene in transformed lines showed higher photosynthetic efficiency with lower water use efficiency which measured in term of $\Delta^{13}C$ which was low(17‰) in transformed plants (Bakshi *et al*., 2017) [4].

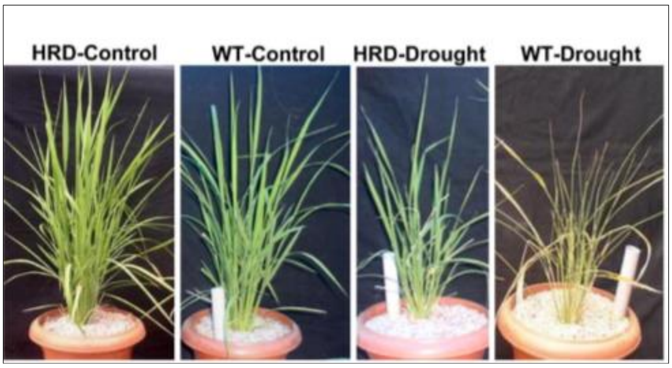

Fig 2: Phenotype of HRD overexpression in rice

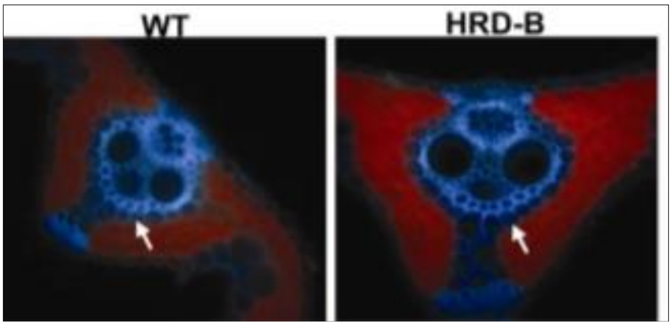

Fig 3: Leaf cross section of HRD over expressed line (Karaba *et al.*, 2007) [18].

2. Activation tagging

Gain of function mutagenesis through activation tagging used as alternative approach to loss function mutagenesis. Activation tagging is suitable for Japonica than Indica due to recalcitrant nature of Indica seed. Tagging of ribosomal protein is a new category of activation tagging which studied by Moin *et al*., (2016) [21] to understand the stress tolerance capacity of mutant indica rice varieties under water limiting condition. The vector used for the study was PSQ5 and obtained enhancer sequence from CaMV35S promoter. Callus transformation method used for the transfer of vector in to the rice. The results showed that mutants recorded better yield, tiller number, number panicle and seed yield than wild type. Percentage of $\Delta^{13}C$ measured was high for wild type (22.05%) compared to mutant, which indicate lower water use efficiency of wild type than mutants. As a continuation of this study Moin *et al*., (2017) [22] identified ribosomal protein large (RPL) gene family can be manipulated to improve water use efficiency, fresh weight, root length, increase in proline and chlorophyll content of rice under drought and salinity stress.

3. Backcross breeding

Maintaining leaf turgor and carbon metabolism are two adaptive mechanism developed by tolerant plants under water limited condition. This was evidently showed in a study conducted by Dharmappa *et al*., (2019) [6]. Introgression of water mining root and water use efficiency trait in to IR-64 rice variety. AC39020 was the donor parent used for root mining trait whereas for water use efficiency IET16348 was selected. Introgression lines developed through marker assisted back cross breeding. The desired plant achieved after 3 backcross and selfing. The resultant plant showed 53% and 23.5% increment in root weight and root length respectively and 53% and 63% higher yield obtained at 100% and 60% field capacity. Carbon isotope discrimination was very low for introgressed line indicate water use efficiency and yield were enhanced in trait introgressed lines which is quite evident in water limiting condition (Fig 4). In a study, association mapping of 173 diverse rice lines were evaluated to find out QTL for root and water use efficiency characters. The results showed that 9 and 16 markers each responsible for carbon isotope discrimination and root length respectively (Raju *et al*., 2016) [25].

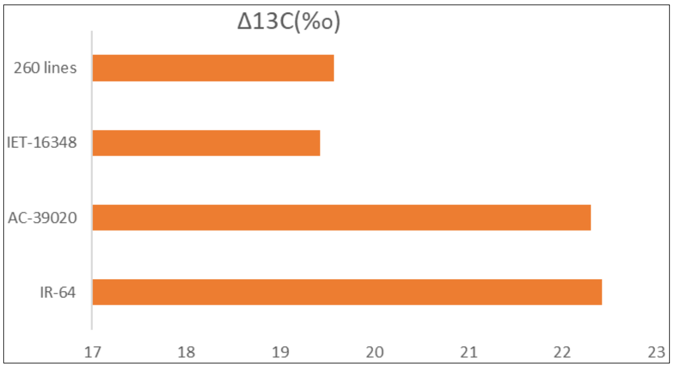

Fig 4: Carbon isotope discrimination between parents and TIL (Dharmappa *et al*., 2019) [6].

B.Physiological approaches

1. Endophytic bacteria

Recent study revealed that Salicaceae endophytes enhanced water use efficiency of rice. Rho *et al*., (2018) [26] isolated the strains of diazotropic endophytic bacteria and yeast such as WP1, WP5, WP9, WP19, WP13, WW5, WW7C and PTD from plants like cotton wood, wild willow and hybrid poplar. These strains have the capacity to amplify nifH marker gene which is responsible for the enzyme nitrogenase reductase in the nitrogen fixation led more biomass accumulation. These strains inoculated plants also reduced stomatal conductance and stomatal density of rice during day time which in turn increased water use efficiency, this effect pronounced under water stress condition.

2. Polyamine, Selenium and *Trichoderma* sp application

Among extreme climate condition, drought is a serious stress this will hamper soil and plant water status. In a study to alleviate the negative impact of drought stress, polyamines like putresine, spermine and spermidine were applied exogenously (seed priming, foliar application). Results showed that net photosynthetic rate and biomass yield were increased, this is because of maintenance of leaf water status of the plant through water use efficiency Fig.5 (Farooq *et al*., 2009) [10]. In another study exogenous application of Selenium (Se) at the rate of $2mgKg^{-1}$ increased water use efficiency, net photosynthetic rate and antioxidant activity of rice grown under water stress condition (Andrade *et al*., 2018). Effect of different *Trichoderma* sp on rice growth were evaluated in a study revealed that *Trichoderma* sp treated plants showed higher growth and physiological activity compared to control. Among various isolates of *Trichoderma* sp, local isolate SL2 treated plants showed higher root biomass and intrincic water use efficiency (Doni *et al*., 2014) [8]. Gypsom application improved water use efficiency and soil properties compared to control in saline sodic soil under rice cultivation (Hafez *et al*., 2015) [14].

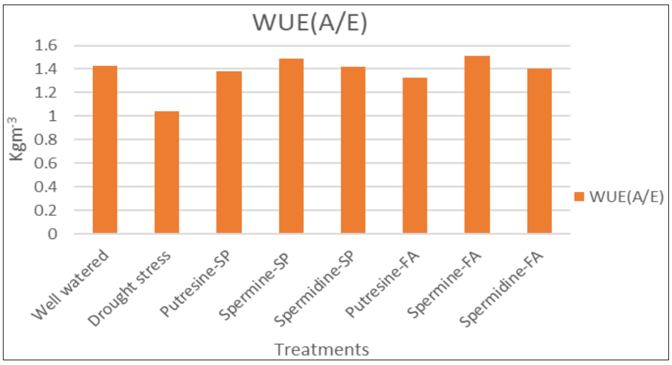

Fig 5: Water use efficiency under polyamine treatment (Farooq *et al*., 2009) [10].

3. Leaf hair modification

One of the morphological character which changes leaf water use efficiency is leaf hair. In a study plant breeders developed an introgression line through back cross breeding called IL-hairy, which possess more leaf hair. IL-hairy was the progeny of parental line IR-24 (hair less) and IRGC105715 is the wild accession of Oryza nivara have hairs on the leaf. Scientist identified the gene responsible for the hairiness using simple sequence repeat (SSR) markers and named as BLANKET LEAF (BKL) and it was located between RM 3567 and RM 7243 in chromosome number 6 in BC_5F_3 population. IR-lines have significantly higher water use efficiency under high and moderate light intensity than parental line however its photosynthetic rate was lesser compared to IR 24 this can be used for water saving cultivation system (Fig 6) (Hamaoka *et al*., 2017) [15].

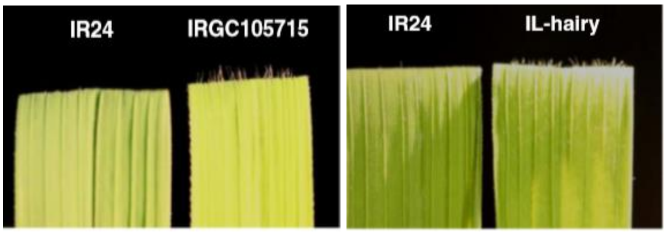

Fig 6: Comparison of leaf hair between parental line and Introgressed Line (Hamaoka *et al*., 2017) [15].

4. Aerobic rice
Kato *et al*., 2009 studied the difference in yield potential between aerobic and flooded high yielding rice varieties in Japan. The results showed that aerobic rice sustained yield under less water than flooded condition and water productivity measured for aerobic rice was 0.8-1Kgm^{-3} of water. This study added one more option for water conservation system of cultivation

B. Cultural practices
1. Wet seed cultivation
Improvement in rice production technology led the farmers to expense major portion of irrigation water for rice cultivation. Under such circumstances, need arisen to use water effectively for sustaining rice cultivation. Scientist in Philippines developed a wet seed culture method which was superior to traditional transplanted rice culture and the water use efficiency of the method was significantly higher (Table.1) (Bhuniyan *et al*., 1995) [5]. Alternate wetting and drying method also reduced water usage in the rice cultivation even though it reduced yield compared to continuous flooding system (Zhang *et al*., 2012) [32]. System of rice intensification is an another agronomical practice which improved both yield and water use efficiency (Zhao *et al*., 2010) [33].

Table 1: Water use efficiency of wet seeded rice and transplanted rice (Redrawn from Bhuniyan *et al*., 1995) [5].

Water regime	Water use efficiency(kgm^{-3})	
	Wet seeded rice	Transplanted rice
5-7cm standing water	5.13	5.28
2cm every alternate days	6.18	6.12
2cm every 4 days	7.56	5.75
5cm every 5 days	3.93	3.32
Average	5.7	5.11

2. Mulching
Flooding cultivation is the common, widely accepted cultivation practice in rice production. The disadvantage of this system is that, it require ample amount of water during entire life cycle of rice. Non flooded mulching cultivation was experimented in Indica rice hybrid Shanyou, revealed that straw mulched plants showed similar yield as traditional flooding cultivation. Mulching reduced tiller number in early stages of growth but later stage it performed better than non-mulched plants. This is due to increase in chlorophyll content, increased photosynthetic rate of flag leaf and root growth which retained in the last stage of plant growth therefore this method can be approached as water saving cultivation in rice (Xu *et al*., 2007) [31]. In another study Fawibe *et al*. (2020) [11] evaluated water use efficiency of rice cultivar Koshihikari and Norin 24, low land and upland rice cultivars respectively grown under continuous flooding and drip irrigation with plastic mulch(DPD). The results showed that the water use efficiency of Koshihikari and Norin 24 increased by 50% and 70% respectively under DPD compared to continuous flooding, indicate Fe deficient and water limited condition drip irrigation with plastic mulch in rice is a promising approach to sustain yield. Similar study of plastic mulching with drip irrigation on rice plants were conducted by he *et al*., (2013) [16].

Conclusion
There is a wide scope to improve water use efficiency in rice to sustain its yield under water limited condition. Key strategies used to improve water use efficiency are genetic transformation, wet seed cultivation, polyamine application, mulching, using endophytic bacteria, improve morphological adaptation like leaf hair, aerobic rice cultivation, activation tagging and backcross breeding. But care should be taken during water storage, transportation and irrigation to reduce wastage of water. The holistic approach of agronomy, physiology, breeding and biotechnology will help to conserve more water that can be used efficiently for rice production.

References
1. Allen RG, Pereira LS, Raes, D, Smith, M. Crop evapotranspiration guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, 1998.
2. Allen MR, Dube OP, Solecki W, Aragón-Durand F, Cramer W, Humphrey S *et al*. Framing and Context. In: Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press, 2018.
3. Andrade FR, da Silva GN, Guimarães KC, Barreto HBF, de Souza KRD, Guilherme LRG, Faquin V, Reis AR, dos, Selenium protects rice plants from water deficit stress. Ecotoxicology and Environmental Safety. 2018; 164:562–570. https://doi.org/10.1016/j.ecoenv.2018.08.022
4. Bakshi A, Moin M, Kumar MU, Reddy, ABM, Ren M, Datla R *et al*. Ectopic expression of Arabidopsis Target of Rapamycin (AtTOR) improves water-use efficiency and yield potential in rice. Sci Rep. 2017; 7:42835. https://doi.org/10.1038/srep42835
5. Bhuiyan SI, Sattar MA, Khan MAK. Improving water use efficiency in rice irrigation through wet-seeding. Irrig Sci, 1995, 16. https://doi.org/10.1007/BF00208389
6. Dharmappa PM, Doddaraju P, Malagondanahalli MV, Rangappa RB, Mallikarjuna NM, Rajendrareddy SH *et al*. Introgression of Root and Water Use Efficiency Traits Enhances Water Productivity: An Evidence for Physiological Breeding in Rice (*Oryza sativa* L.). Rice. 2019; 12:14. https://doi.org/10.1186/s12284-019-0268-z
7. Dingkuhn M, Farquhar G, De DS, O'Toole J, Datta SK. Discrimination of 13C among upland rices having different water use efficiencies. Aust. J Agric. Res. 1991; 42:1123. https://doi.org/10.1071/AR9911123
8. Doni F, Isahak A, Che Mohd Zain CR, Wan Yusoff WM. Physiological and growth response of rice plants (*Oryza*

sativa L.) to Trichoderma spp. inoculants. AMB Expr. 2014; 4:45. https://doi.org/10.1186/s13568-014-0045-8
9. Farquhar G, Richards R. Isotopic Composition of Plant Carbon Correlates with Water-Use Efficiency of Wheat Genotypes. Australian Journal of Plant Physiology, 1984, 11(6).
10. Farooq M, Wahid A, Lee DJ. Exogenously applied polyamines increase drought tolerance of rice by improving leaf water status, photosynthesis and membrane properties. Acta Physiol Plant. 2009; 31:937–945. https://doi.org/10.1007/s11738-009-0307-2
11. Fawibe OO, Hiramatsu M, Taguchi Y, Wang J, Isoda A. Grain yield, water-use efficiency, and physiological characteristics of rice cultivars under drip irrigation with plastic-film-mulch. Journal of Crop Improvement. 2020; 34:414–436. https://doi.org/10.1080/15427528.2020.1725701
12. Flexas J. Genetic improvement of leaf photosynthesis and intrinsic water use efficiency in C 3 plants: Why so much little success? Plant Science. 2016; 251:155–161.
13. Gajri PR, Prihar SS, Arora VK. Interdependence of nitrogen and irrigation effects on growth and input-use efficiencies in wheat. Field Crops Research. 1993; 31:71-86.
14. Hafez EM, Hassan WHAE, Gaafar IA, Seleiman MF. Effect of Gypsum Application and Irrigation Intervals on Clay Saline-Sodic Soil Characterization, Rice Water Use Efficiency, Growth, and Yield. JAS. 2015; 7:208. https://doi.org/10.5539/jas.v7n12p208
15. Hamaoka N, Yasui H, Yamagata Y, Inoue Y, Furuya N, Araki T *et al*. A hairy-leaf gene, BLANKET LEAF, of wild Oryza nivara increases photosynthetic water use efficiency in rice. Rice. 2017; 10:20. https://doi.org/10.1186/s12284-017-0158-1
16. He H, Ma F, Yang R, Chen L, Jia B, Cui J *et al*. Rice Performance and Water Use Efficiency under Plastic Mulching with Drip Irrigation. PLoS ONE. 2013; 8:e83103. https://doi.org/10.1371/journal.pone.0083103
17. Intergovernmental Panel on Climate Change (IPCC) fourth assessment report. Climate Change: Impacts, Adaptation and Vulnerability; The Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2007.
18. Karaba A, Dixit S, Greco R, Aharoni A, Trijatmiko KR, Marsch-Martine N *et al*. Improvement of water use efficiency in rice by expression of HARDY, an Arabidopsis drought and salt tolerance gene. Proceedings of the National Academy of Sciences. 2007; 104:15270–15275. https://doi.org/10.1073/pnas.0707294104
19. Kato Y, Okami M, Katsura K. Yield potential and water use efficiency of aerobic rice (*Oryza sativa* L.) in Japan. Field Crops Research. 2009; 113:328–334. https://doi.org/10.1016/j.fcr.2009.06.010
20. Kijne JW, Barker R, Molden D. (eds.). Water productivity in agriculture: Limits and opportunities for improvements. Comprehensive Assessment of Water Management in Agriculture Series 1, CABI International, UK, 2003.
21. Moin M, Bakshi A, Saha A, Udaya Kumar M, Reddy AR, Rao KV *et al*. Activation tagging in *indica* rice identifies ribosomal proteins as potential targets for manipulation of water-use efficiency and abiotic stress tolerance in plants: Activation tagging identifies ribosomal protein genes. Plant, Cell & Environment. 2016; 39:2440–2459. https://doi.org/10.1111/pce.12796
22. Moin M, Bakshi, A, Madhav MS, Kirti PB. Expression Profiling of Ribosomal Protein Gene Family in Dehydration Stress Responses and Characterization of Transgenic Rice Plants Overexpressing RPL23A for Water-Use Efficiency and Tolerance to Drought and Salt Stresses. Front. Chem. 2017; 5:97. https://doi.org/10.3389/fchem.2017.00097
23. Morrison JIL, Baker NR, Mullineaux PM, Davies WJ. Improving water use in crop production. Phil. Trans. R. Soc. 2008; B363:639–658
24. Nada RM, Abogadallah GM. Aquaporins are major determinants of water use efficiency of rice plants in the field. Plant Science. 2014; 227:165–180. https://doi.org/10.1016/j.plantsci.2014.08.006
25. Raju BR, Mohankumar MV, Sumanth KK, Rajanna MP, Udayakumar M, Prasad TG *et al*. Discovery of QTLs for water mining and water use efficiency traits in rice under water-limited condition through association mapping. Mol Breeding. 2016; 36:35. https://doi.org/10.1007/s11032-016-0457-z
26. Rho H, Van Epps V, Wegley N, Doty SL, Kim SH. Salicaceae Endophytes Modulate Stomatal Behavior and Increase Water Use Efficiency in Rice. Front. Plant Sci. 2018; 9:188. https://doi.org/10.3389/fpls.2018.00188
27. Sinclair TR, Tanner CB, Bennnet JM. Water use efficiency in crop production. Bioscience 1984; 34:36-40.
28. This D, Comstock J, Courtois B, Xu Y, Ahmadi N, Vonhof WM *et al*. Genetic Analysis of Water Use Efficiency in Rice (*Oryza sativa* L.) at the Leaf Level. Rice. 2010; 3:72–86. https://doi.org/10.1007/s12284-010-9036-9
29. Winter K, Aranda J, Holtum JAM. Carbon isotope composition and water-use efficiency in plants with crassulacean acid metabolism. Functional Plant Biol. 2005; 32:381. https://doi.org/10.1071/FP04123
30. Wright GC, Hubick KT, Farquhar GD. Discrimination in Carbon Isotopes of Leaves Correlates with Water-Use Efficiency of Field-Grown Peanut Cultivars. Australian Journal of Plant Physiology. 1988; 15(6):815-825.
31. Xu GW, Zhang ZC, Zhang JH, Yang JC. Much Improved Water Use Efficiency of Rice under Non-Flooded Mulching Cultivation. Journal of Integrative Plant Biology. 2007; 49:1527–1534. https://doi.org/10.1111/j.1672-9072.2007.00558.x
32. Zhang Y, Tang Q, Peng S, Xing D, Qin J, Laza RC *et al*. Water Use Efficiency and Physiological Response of Rice Cultivars under Alternate Wetting and Drying Conditions. The Scientific World Journal, 2012, 1–10. https://doi.org/10.1100/2012/287907
33. Zhao L, Wu L, Li Y, Animesh S, Zhu D, Uphoff N. Comparisons of Yield, Water Use Efficiency, and Soil Microbial Biomass as Affected by the System of Rice Intensification. Communications in Soil Science and Plant Analysis. 2010; 41:1–12. https://doi.org/10.1080/00103620903360247