Agricultural water use efficiency to adapt climate change in Indo-Gangetic plains of south-east Asia

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ABSTRACT

Enhancing crop water productivity by genetic improvements or agronomic manipulations and reducing evapotranspiration losses from soil and plant surface is the need of the hour. Selection and breeding of traits which lead to increase in crop and water productivity like early maturing and stress tolerant cultivars with deep and thick root system, hairy leaves and increase in partitioning of assimilates towards grains etc. can help in increasing the water productivity. Different management options like, alteration in planting time, more water efficient planting methods, tillage practices, irrigation management, intercropping, use of anti-transpirants, row orientation, planting geometry and application of mulches and shelter belts can play important role for sustainability of water resources and crop productivity. However, the best option varies according to the location, prevailing weather conditions as well as social and economic conditions of the farmers.

Keywords: Climate change, Crop water productivity, Evapotranspiration, Indo-Gangetic plains, Irrigation management

Climate Change is a serious global environmental concern. The globally averaged temperature data shows a warming of 0.85°C over the period 1880–2012 and is likely to increase further by 0.3–0.7°C by 2035 (IPCC 2014). Developing countries are more vulnerable to such changes as they have limited resources to cope up with the disasters (Majumder et al. 2016a). Minimum temperature has been observed to increase @ 0.05°C per year in Punjab (Kingra et al. 2017). Climate change is severely affecting the important natural resources including water (Chatterjee et al. 2012) and has the potential to influence the productivity of agriculture significantly (Kingra 2016a, Kingra 2016b). Climate change might cause increased crop failure and more frequent incidences of pests (Chauhan et al. 2014). Changes in precipitation frequency and intensity affect run-off and the occurrence of floods and droughts (IPCC 2007). Majumder et al. (2016b) reported that increase in water requirements under warming scenarios will put more pressure on water resources in north-west India.

Increasing CO2 increases WUE until the leaf is exposed to temperatures exceeding the optimum for growth and then WUE begins to decline (Hatfield and Donald 2019) (Table 1). Saha et al. (2018) reported that an increase in the temperature by 0.5, 1.0, 1.5 and 2.0°C might increase the ET0 by 0.72, 1.82, 2.91 and 4.01%, respectively and water requirement of barley by 1.27, 3.10, 4.26 and 5.56% in central Punjab. Kingra and Kukal (2013) reported increase in water demand of wheat by 45mm with increase in temperature by 1°C. Effective management for water use is the only way to save water for increasing the irrigated agriculture (Boutraa 2010). Crop water requirement provide key information for irrigation scheduling, water resource planning and future decision making (Yang et al. 2013). Temperature, net radiation and wind speed have positive and vapour pressure has negative relation with PET (Kingra 2018). Kaur et al. (2018) observed positive correlation of PET of kharif maize with daytime temperature (r=0.76 and 0.49) and negative with relative humidity (r=-0.68 and -0.89) in central and sub-mountainous Punjab. Potential evapotranspiration (PET) of wheat is significantly affected by maximum temperature (R2=0.79), rainfall (R2=0.58), number of rainy days (R2=0.55) and their interactive effect (R2=0.83) (Kingra and Kukal 2013). Kang et al. (2009) reported that with temperature increasing and precipitation fluctuating, water availability and crop production will decrease in the future. Khan et al. (2009) reported that climate change is creating a new level of uncertainty in water governance, requiring accelerated research to avoid water-related stresses. Kingra et al. (2019) reported that as the water productivity of rice and wheat was negatively
correlated with actual evapotranspiration, thus, by reducing the evaporation losses in the fields, there is scope for enhancing their \( WP_{ET} \).

**Ways to improve water productivity**

The agricultural community has a challenge of increasing food production by more than 70% to meet demand from the global population increase by the mid-21st century (Kannan and Anandad 2020). Climate change will affect plant growth, but we have opportunities to enhance WUE through crop selection and cultural practices to offset the impact of a changing climate (Hatfield and Donald 2019) (Table 2). The improvements in crop water productivity by genetic or agronomic manipulations is the need of the hour (Fig 1). Rani et al. (2017) reported that adjustments in sowing time, mulch application and need based irrigation application are effective for improving water use efficiency of maize. Some management strategies helpful in improving crop water productivity are as given below:

**Selection of improved varieties:** Ruggiero et al. (2017) emphasized the need for identification and characterization of key genetic and physiological processes involved in water uptake and loss. Brar et al. (2012) reported that cultivation of medium duration varieties of paddy during the low evaporation period can check the over draft of underground water. Similarly, hairiness increases the light reflectance and reduces water loss by increasing the boundary layer resistance (Farooq et al. 2009).

**Improving assimilate partitioning to grain:** Blankenagel et al. (2018) reported that breeding for WUE and high yield is a major challenge as the factors influencing the trait under field conditions are complex, including different scenarios of water availability. A metabolite profiling analysis of the flag leaves of 292 *indica* rice accessions has led to the identification of new molecular markers for drought tolerance and sensitivity in terms of grain yield (Melandri et al. 2020 and Sulipce 2020).

**Alteration in planting date:** Brar et al. (2012) also reported that delay in transplanting from June 15 to June 25 or July 5 did not show any adverse influence on yield and quality of rice, but irrigation water saving was 4.6–14.0% higher and total crop water productivity was 9.8–19.2%.

Table 1: Impact of climate change on crop water requirements and water use efficiency

<table>
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<tr>
<th>Crop/parameter</th>
<th>Location</th>
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<td>Cotton</td>
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<td>Zhu et al. (2020)</td>
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higher. Kingra and Kaur (2012) reported decrease in yield and water use efficiency of Brassica species with delay in sowing. Singh and Kingra (2015) reported higher water productivity of 26th October and 12th November sown wheat as compared to that sown on 28th November. Franke et al. (2020) also recommended earlier planting of potato in South Africa to maximise yield and water use efficiency under climate change.

Optimizing plant population and planting method: Ali et al. (2013a) concluded that planting in 11 cm wide rows under conventional tillage at 100% ET₀ may serve as an appropriate technology for enhancing productivity of late sown wheat under limited water supplies. Chen et al. (2015) observed that plant growth and grain yield decreased as lateral spacing increased in wheat. Devkota et al. (2013) also reported significantly higher water productivity of wheat under permanent beds as compared to conventional tillage. Kingra and Mahey (2013) also observed higher evapotranspiration losses in flat than bed planting in wheat. Significantly higher leaf area and dry weight of bulbs in kharif onion was observed in crop raised on beds with 2.5 t/ha of crop residues compared to the rest of treatments and it recorded significantly lower fresh and dry weight of weeds/m² (Kaur 2017).

Fig 1 Management strategies for sustainable water management in agriculture under changing climatic conditions.
Laser land leveling: Laser land leveling results in water savings up to 15-30% (conserveagri.org 2009). It saved irrigation water and energy by 24% with 4.25% higher yields (Kaur et al. 2012). Wagan et al. (2015) reported about 21% of irrigation water saving with the use of laser leveling technology. Shahani et al. (2016) revealed about 21% irrigation water saving by the adoption of laser leveling technology along with higher yield and profit margins.

Increasing soil fertility/fertilization: Pala et al. (2007) concluded that nitrogen application could increase the ability of crop to utilize available water. Kundu et al. (2008) observed that higher dosed of phosphorous increased root density and enhanced the magnitude of root water uptake. Majumder et al. (2016b) reported that need based irrigation scheduling in along with sub-surface manuring is helpful in managing crop water productivity under limiting water availability in north-west India.

Mulch application: Mulch application leads to reduction in evaporation, stabilization of temperature and improvement in the moisture status of the soil (Kingra and Kaur 2017). Ram et al. (2013) reported that rice straw mulch increased water use efficiency of wheat by 14-34% under different irrigation levels. Kaur and Brar (2016) reported 125.2% higher turmeric yield and 50% saving in irrigation water with mulch application @ 6 t/ha. Li et al. (2013) concluded that the soil moisture and temperature were improved and maize yields with plastic film, biodegradable film, maize straw were significantly increased by 13.0%, 13.8% and 15.0%. Singh et al. (2011) reported that retention of rice residues as surface mulch could be beneficial for moisture conservation and yield. Mulch application reduced soil evaporation during wheat growing season by 35 and 40 mm in relatively high and low rainfall years. Buttar et al. (2018) also reported positive impact of mulch on yield attributing characters and grain yield.

Conservation tillage: Su et al. (2007) observed no tillage and subsoil tillage with mulch to be optimum for increasing water storage, wheat yields and water use efficiency. Chakraborty et al. (2008) reported rice husk mulching is beneficial for wheat leading to higher grain yield and water use efficiency. Chi et al. (2016) reported that no-till had greater ratio of transpiration to evapotranspiration (T/ET) in bean crop.

Seedlings planting age and seed priming: Aslam et al. (2015) reported that seedling age plays an important role in yield contributing parameters leading to higher paddy yield. Chapagain and Yamaji (2010) observed synergistic effects of younger seedlings and wider spacing that led to higher productivity under system of rice intensification. Ali et al. (2013b) reported that the use of on-farm priming or hydro-priming of seeds for 12 h could improve grain yields in late-sown wheat. Meena et al. (2013) reported that priming techniques along with seeding at sub-optimal soil moisture level proved an efficient technique for enhancing water productivity of wheat (1.70 kg/m$^3$) as compared to seeding at optimum moisture level without priming (1.37 kg/m$^3$).

Water harvesting: The ridge furrow rainwater harvesting (RFRH) system with different ridge covering materials as mulch is a valuable technique for enhancing seed filling rates and maize productivity (Ali et al. 2016). Lian et al. (2016) also reported that ridge and furrow rainfall harvesting (RFRH) system along with appropriate fertilizer dose is effective for improving rainwater utilization, crop productivity and water use efficiency. As climate change is likely to increase rainfall variability and evaporation in future, thus rainfall harvesting may become a key intervention to cope with water scarcity (Yazar and Ali 2017).

Irrigation management: Butter et al. (2007) observed that delayed first irrigation resulted in 28% increase in seed cotton yield and 16% in stick biomass. Tang et al. (2010) reported that partial root zone irrigation (PRI) in cotton can substantially reduce irrigation amount. Barrios-Masias and Jackson (2016) reported that partial root zone drying (PRD) improves crop water productivity (WP), and can be applied as alternate furrow irrigation (AFI). Kusakabe et al. (2016) suggested that PRD can be economically beneficial for citrus growers who use double-line drip irrigation systems. Barideh et al. (2018) observed 28% and 32% water saving in corn with fixed partial root zone irrigation (FPRI) and alternate partial root zone irrigation (APRI), respectively, over conventional irrigation (CI). Chapagain and Yamaji (2010) observed that irrigation with alternate drying and wetting intervals (AWDI) saved 28% of water without reducing grain yield. Dejonge et al. (2012) also reported that due to limited water resources for agriculture crop can be intentionally stressed during specific growth stages to maximize water use efficiency.

Kaur and Brar (2016) reported 40% water saving in turmeric under drip irrigation. Qin et al. (2016) revealed that drip irrigation can provide adequate water and nutrition and the crop growth can be significantly enhanced. To achieve maximum WP, one, two and three irrigations (i.e., 70, 150 and 200 mm per season) were recommended for wheat in wet, medium and dry seasons, respectively (Wang et al. 2010). Chen et al. (2010) reported one, two and three irrigations for wheat in wet, medium and dry seasons, respectively, for wheat and one and two irrigations in medium and dry seasons for maize, while no irrigation was needed in wet season.

Use of antitranspirants and shelterbelts: Antitranspirants films increase stomatal resistance (Kettlewell et al. 2010). ABA induced changes constitute an improvement in water-use efficiency in greengram (Dhishnamurthi et al. 2014). Boari et al. (2016) observed that Kaolin spray increased the water use efficiency of tomato. Javan et al. (2013) observed significant increase in 1000-seed weight and seed yield of soybean with the spray of Kaolin, Chitosan and castorbean oil. Reduced water losses by shelterbelts can encourage early germination, plant growth and hence yield and water use efficiency. Campi et al. (2009) reported increase in water use efficiency of wheat within a distance of 18 times the wind break. Hana (2010) also reported significant effect of shelterbelts in conserving soil moisture.

Weed control: Weeds consume water intended for crops,
leading to higher consumption and more evaporative water loss (Zimdahl 2013). Croissant et al. (2014) reported that weeds cause higher ET rates as compared to corn during its early development stage. Abouziena et al. (2015) also reported that proper weed control enhances available soil water for crop production.

Conclusion

The study concluded that increase in heat and water stress under future climate change scenarios are likely to have adverse effects on water availability, crop yields and water productivity. Thus, there is dire need for identification and characterization of key genetic and physiological processes involved in water uptake and loss as these traits represent novel opportunities and strategies for genetic improvement of WUE and drought tolerance in crops. In addition to this, agronomic interventions such as appropriate sowing time, plant population, planting methods, fertilization, mulch application, conservation agriculture, age of seedlings, seed priming, water harvesting and irrigation management etc. need to be adopted for judicious use of water resources to attain higher crop yield and maximize water productivity for food security.

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