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Concept and Consequence of Evapotranspiration for Sustainable Crop Production in the Era of Climate Change

Rajan Bhatt and Akbar Hossain

Abstract

The chapter provides an inclusive information related to the adverse effect of climate change on sustainable crop production through understanding evaporation, transpiration as well as evapotranspiration. It is anticipated that water availability in arid and semi-arid regions across the world will decrease, due to lack of rainfall and increase the temperature which leads to increase in the dry areas. Since climate change will impact on soil water balance that leads to change in evaporation and plant transpiration. While, with the increasing temperature, lack of precipitation and soils water unavailability, crop production will likely to decrease through shortening the crop growth cycle. While soils with high water holding capacity and crop cultivars which are tolerant to adverse effect as well as the application of improved management strategies will be better to reduce the impact of drought. Similarly, if the irrigated areas will be expanded, the total crop production will be increased that ultimately lead to increase the food security of increasing population.

Keywords: evapotranspiration, changing climate, crop production, food security, increasing population

1. Introduction

Climate change has emerged as the most prominent of the global environmental issues and there is a need to evaluate its impact on the agriculture as the temperature is projected to increase in near future [1]. Furthermore, climate change provides more energy that causes to change liquid to gaseous form as well as occurs more evaporation (E) to which reduces the share of transpiration. Evaporation is the unproductive loss of water and is mainly responsible for the lower land as well as water productivity [2], while transpiration (T) is the desired component as greater the transpiration (T) greater will be nutrient inflow along with the water, resulted in higher grain yields. For occurring E, three things are required, viz. sufficient soil moisture, vapor pressure gradient and energy, to cause the phase change and lack of anyone, E will not be happened [3]. Among different soil water balance components, evapotranspiration (ET) is an important one which further decides the water use efficiency. Furthermore, ET shares in total remain the almost similar [4].

Therefore, without appropriate technologies, farmers will find it extremely difficulties to operate climate-smart agricultural to meet the food demand of

increasing population. In the meantime, scientists across the world to regions working on it and tried to invent improved technologies which could partition greater share of the total ET water to T by diverting share of E. The surface water in the region continue to be delivered through old traditional canal and on-farm conveyance networks those have earthen bunds and are unlined resulting in very low water use efficiency (30–50%). Generally, irrigators usually cut off the supply when the advance is complete without considering the additional irrigation water infiltrates at the entrance especially when the soil is opened up with pre-seeding tillage. Thus large non-uniformities in water application in addition to over-irrigation. In our situation, generally plot size of 250 m² in coarse texture and 500 m² in medium to fine texture is recommended for wheat [5] for improving the water use efficiency. For cotton furrow irrigation could save 100–150 mm of irrigation water [6] as it cuts down the share of E. Even the broad beds spaced at 1.35 m and planting cotton in furrows in paired rows improved its yield by 44% and saved 40% irrigation water as compared with row spacing of 0.75 m in flatbed system [7]. Micro-irrigation especially drip, mini-sprinklers and sub-irrigation systems designed to apply small and frequent irrigations, are now emerging as ideal technologies which cut off E share and partition greater share of the ET to the T component. As the water is being applied to the root zone rather than entire field and both unproductive losses, viz. evaporation (E) and deep drainage (D) is considerably reduced, irrigation efficiencies as high as 95 and 80% are achieved with drip and sprinklers systems, respectively. The overall water savings with drip systems ranged between 50 and 65% in vegetables [8] along with higher fertilizer use efficiency and better quality of the product. The government has introduced subsidies to the extent of 75%, still, the drip system does not seem to be adopted at the desired levels.

For upland crops, viz. wheat, maize, potato, etc., effects of E demand and rainfall concept for timing irrigation to crops was put forward in 1970s [9, 10]. It is a deficit-irrigation approach that induces deeper rooting for promoting utilization of profile stored water especially the sub-soil water. Heavy pre-sowing irrigation followed by irrigations at IW/PAN-E ratio of 0.75 [11] and last irrigation during mid-March by charging soil profile to 80–100% of water depletion [9, 10] further improves water productivity.

Thus, efforts have also been made to compute crop sensitivity to water stress by relating yield with ET or T. Water deficits mainly damage the crops during meiosis of pollen mother cells or around anthesis. Therefore, sensitive stages in different crops need to be identified to mitigate the adverse effects of limited irrigation. Generally, at present scientists advocate different technologies, viz. mulching, crop diversification, correct T time of rice, bed planting, zero tillage, short duration crop cultivars to partition greater share of the ET water share to the T by depressing E in one or other way. These technologies have a substantial scope in improving irrigation efficiency and reducing energy for groundwater withdrawal. In the present chapter, we tried to understand the concept and consequences of evapotranspiration for sustainable crop production in the era of climate change. A detailed description of evaporation, transpiration and evapotranspiration and their importance for sustainable agriculture are highlighted by the following sub-heading.

2. Concept of evaporation, transpiration, and evapotranspiration and its relation to crop productivity

Evaporation is the physical process through which liquid water is converted to water vapor. The rate of E depends on the saturated vapor pressure of the liquid and increases with increase in temperature until the atmospheric pressure at the boiling point [12].

Transpiration is the process by which moisture is carried through plants from roots to small pores on the underside of leaves, where it changes to vapor and is released to the atmosphere. Transpiration is principally E of water to the atmosphere from plants roots to small pores on the underside of leaves. Another type of water loss from the uninjured leaf or stem of the plant, mainly by stomata is called guttation [13]. Nearly 10% of the moisture available in the atmosphere is from the T process [14]. The remaining 90% is mainly from the E process from different water bodies [15, 16]. reported that the T is attained by the movement of water, at the vapor phase through the conductor system from the roots to the leaves of the plant, as a function of a water potential gradient from the soil (ψ_{soil}) to the air (ψ_{air}) as shown in **Figure 1**.

In general, ET is the sum of E and T. It is the simultaneous process of water transfer to the atmosphere both by soil water E and plants T. The study found that during a growing season, a leaf will transpire many times more water than its own weight. An acre of corn gives off about 11,400–15,100 l of water each day, and a large oak tree can transpire about 1,51,000 l per year [13] (USGS, 2016).

Depending on the vegetation conditions, size of the vegetated area, and soil water supply, different conceptions are to be defined, such as potential, actual, oasis, and crop ET [16]. Such particular terms are described as follows.

2.1 Potential evapotranspiration (ETp)

Potential ET represents the combined loss of water through the plant’s process of T and E of water from the Earth’s surface. Both the processes are influenced by temperature, humidity, sunlight, and wind as well as Earth vegetation. ETp values indicate the amount of water that has been lost, and thus needs to be replaced, through irrigation and/or rainfall [16, 17].

2.2 Actual or real evapotranspiration (ETa)

Actual ET is the amount of water actually utilized by an extensive surface vegetated with grass, at an active growth stage, covering completely the soil surface. ETa is the quantity of water that is actually removed from a surface due to the processes

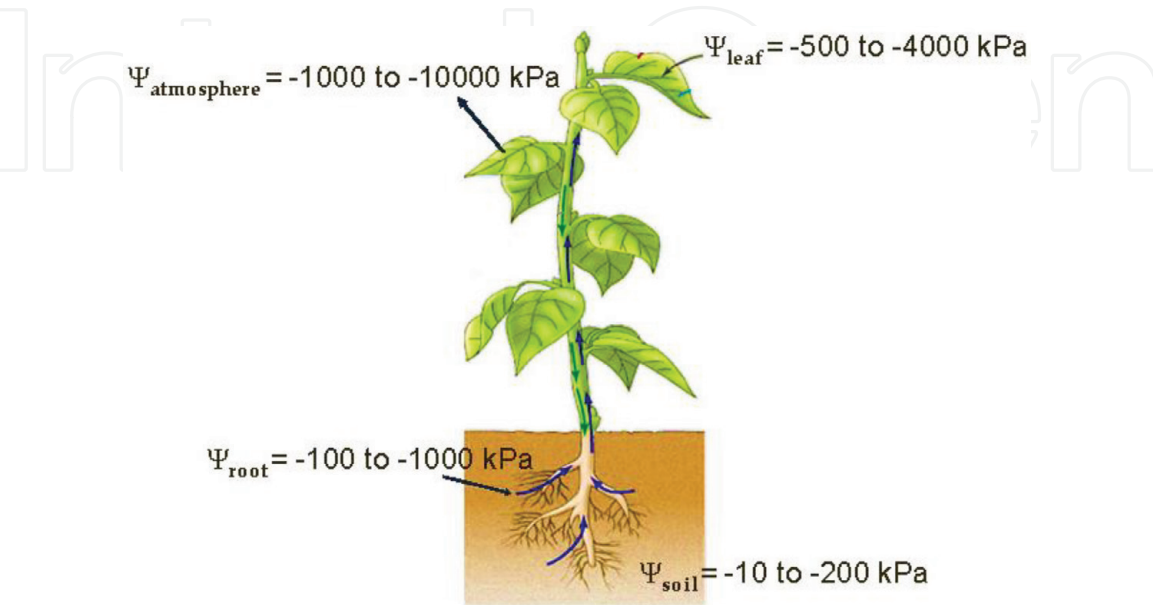


Figure 1.
Schematic representation of the water motion in the soil-plant-atmosphere system under optimal development conditions (adapted from [15, 16]).

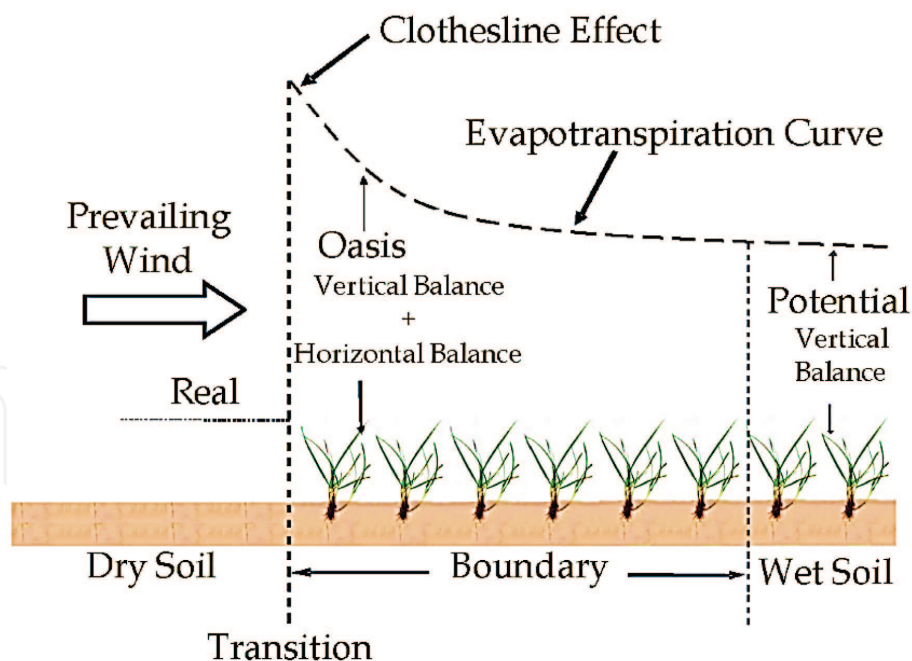


Figure 2.
Schematic representation of the ET_0 and ET_p (adapted from [16, 18]).

of E and T [17]. There is a relation between potential ET and actual ET . Crop water need can be estimated by the following equation: Crop water needs = potential evapotranspiration – actual evapotranspiration.

2.3 Oasis evapotranspiration (ET_0)

Oasis ET is the amount of water consumed by a small irrigated vegetation which is encircled by a widespread dry-area, at which dynamism of water to vapor is come from high temperature in combination with drought [16, 18]. **Figure 2** shows the border area necessary for minimizing the lateral transport of energy from the dry to the wet area (irrigated). At such an area, the ET that will take place is the oasis ET .

2.4 Evapotranspiration (ET_c)

Evapotranspiration is the process by which an amount of water is used by any growth stage of a crop from sowing to harvest, at whatever time there is no water constraint in the soil [13, 16]. ET_c is a function of leaf area (transpiring surface), because the bigger the leaf area (LAI), the higher ET_c will be for the same atmospheric demand [17].

3. Factors affecting evapotranspiration (ET)

Weather parameters, crop characteristics, management and environmental aspects are factors affecting E , T , and ET . Details of these factors are as follows:

3.1 Climatic factors that affecting ET

3.1.1 Radiation

Radiation is the main source of energy for the ET process. It depends on the global solar radiation flux density and vegetation albedo. A darker vegetation

absorbs more incident solar radiation and evapotranspires more [13, 16]. A thorough understanding of the factors controlling the energy balance of a cropped soil enables making accurate estimates or predictions of ET and irrigation water requirements. It also facilitates more effective irrigation water management [19, 20].

3.1.2 Temperature

Over the course of a day, an increase of the air temperature causes an increase on the saturation deficit triggering a higher evaporative demand in the air, and leading to high ET rates [13, 16].

3.1.3 Relative humidity (%RH)

Air relative humidity acts in conjunction with temperature. The higher relative humidity, the lesser the evaporative demand and, therefore, the lower ET [13, 16].

3.1.4 Wind

Advection represents the horizontal transport of energy from a drier area to another more humid, and such additional energy is utilized in the ET process. Wind also helps remove water vapor near the plants to other regions [13, 16].

3.2 Crop factors that affecting ET

Crop factors such as crop species, radiation reflection coefficient, leaf area index (LAI) in different growth stages of the plant, plant height and root depth (depth of the radicular system) are influenced on the crop ET, which are described details as follows:

3.2.1 Crop species

This factor is related to the foliar architecture (spatial distribution of the leaves), internal resistance of the plant to water transport, and other morphological aspects (number, size, and distribution of stomata, etc.), which exert a direct influence on ET [13, 16].

3.2.2 Radiation reflection coefficient

Radiation reflection influences directly net radiation availability for the ET process. The darker the vegetation, the lower the reflection coefficient and the higher net radiation [13, 16].

3.2.3 Leaf area index (LAI) in different growth stages of plant

LAI in different growth stages of a plant is directly related to the size of the transpiring foliar surface, for the larger leaf area the larger the transpiring surface, and the higher the potential for water use [13, 16].

3.2.4 Plant height

Plant height also influences the ET. Taller and rougher plants interact more efficiently with the atmosphere in motion, extracting more energy from the air and, therefore, increasing ET [13, 16].

3.2.5 Rooting depth of plant (depth of the radicular system)

Rooting depth of plant is directly related to the volume of soil explored by the roots, aiming at meeting the atmospheric hydric demand. A superficial radicular system, for exploring a smaller soil volume, keeps the crop more susceptible to drying periods [13, 16].

3.3 Crop management and growing environmental conditions also influence the ET

The following crop management and growing environmental conditions are influenced the crop ET:

3.3.1 Row to row or plant to plant spacing

Usually, intraspecific competition is found between plants/crops of the same species/types for their essential growth elements. A limited spacing between the plant to plant or row to row of the same species or different species of plants/crops, consequences in an intense competition for water, light, nutrient, etc., causing as a consequence an increase on ET [13, 16].

3.3.2 Crop orientation

Crops oriented perpendicularly to predominant winds tend to extract more energy from the air than those oriented in parallel. For regions with constant winds, a solution to prevent the stomata-closing would be the use of windbreaks. A wind-break reduces wind velocities and decreases the ET rate of the field directly beyond the barrier [13, 16].

3.3.3 Soil properties (structure and texture)

Soil texture and soil structure are both unique properties of the soil that will have a profound effect on the behavior of soils. Both the properties influence the crop ET through influencing the water holding capacity of the soils. Clay soils have higher water holding capacity than sandy soils and are proficient of preserving a more persistent crop ET rate for longer [13, 16].

3.3.4 Chemical/physical impediments

Inhibitions system limit the growth of the radicular system of a plant, affecting the root system of plants to explore a wider volume of soil both in dry and rainy seasons. In the rainy season, soil with any physical obstructions gets soaking wet suffocating the roots. While in the dry season, the volume of available water is reduced from the roots of a plant; as a results root system of a plant is deepening into the soil for searching available water [13, 16].

3.4 Interrelationship atmospheric demand: soil water supply

The soil is a dynamic reservoir for available water for growth and development of plants. It is controlling the rate of water use by the plants and continuously in

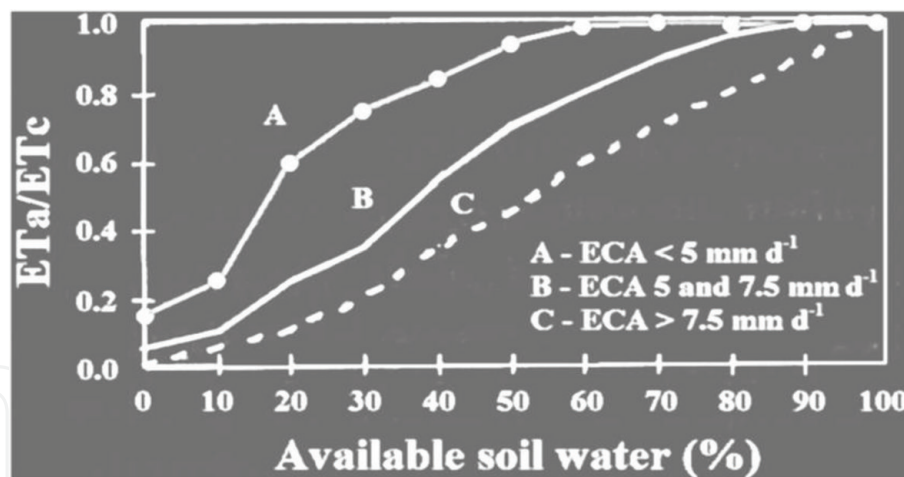


Figure 3.
Relationship between corn relative evapotranspiration (ET_a/ET_c) and soil available water and atmospheric demand expressed by ECA (adapted from [16, 21]).

coincidence with the atmospheric demand. Since the atmospheric demand for water is directing by solar radiation, air humidity, and wind speed (**Figure 3**). Under situation C, in which ECA (by the evaporation from a Class A pan (ECA)) $> 7.5 \text{ mm day}^{-1}$ (high demand); the plants do not manage to extract water at a rate compatible to its needs even under the available soil water, as a result, to avoid drying of the leaves plants temporary close the stomata. Such a condition usually takes place at the hottest hours of the day [13, 16].

4. Interrelation between the intervening period of rice-wheat cropping sequence and ET

“Intervening period” is perhaps the most ignored period in the any crop rotation as scientists are trying to analyze the effects of applied treatments on the land and water productivity, which could be exploited for cultivating the intervening crops, viz. moong and other fodder crops [22–25]. Several investigations were carried out during intervening periods of wheat 2012–2013 and rice 2013; rice 2013 and wheat 2013–2014; wheat 2013–2014 and rice 2014 and rice 2014 and wheat 2014–2015 using time domain reflectometer, electronic tensiometer, soil thermometers (up to 0–10 cm) and mini-lysimeters to delineate soil moisture dynamics as affected by different establishment methods of rice and wheat sequence. Zero tilled wheat plots (ZTW) evaporates 7.6 and 12.8% more, retained 10.3 and 9.4% lower volumetric moisture content at 7.5 cm soil depths and reported to had 28, 18 and 18% and 21, 16 and 17% higher soil tension values at 10, 20 and 30 cm soil depths because of reported 2.2 and 2.1% higher soil temperature than the conventionally tilled (CT) wheat plots during intervening periods after wheat 2012–2013 and wheat 2013–2014. However, after rice 2013, ZT plots reported to conserve 4.0% higher moisture content because of reported 2.3% lesser soil temperature which evaporates 27.6% lesser after rice 2013. On an average, conventional tilled both wheat and direct seeded rice (CTW-DSRCT) plots had 14, 29 and 45% lower SWT values than the zero till wheat and zero till direct seeded rice (ZTW-DSRZT) plots after rice 2013. They also found that after rice in 2014, CTW-DSRZT plots conserved more soil moisture than ZTW-DSRZT, although an exception was found in CTW-DSRCT plots, but were nearly equally and effective for conserving the soil moisture CTW-DSRZT cropping system.

5. Consequences of evapotranspiration for sustainable crop production in the era of climate change

Water moved from the Earth's surface into the atmosphere by evaporation and T the two distinct mechanisms. Evaporation occurs directly from the water bodies where liquid water is transformed into a gaseous state. Recondition for evaporation to occur is when atmospheric humidity is less than the evaporating surface (at 100% relative humidity there is no more evaporation). The evaporation process requires large amounts of energy, viz. 600 calories of heat energy for 1 g of water. Transpiration is the process of water loss from plants through stomata—a small opening found on the underside of leaves that are connected to vascular plant tissues. In most plants, T is a passive process largely controlled by the humidity of the atmosphere and the moisture content of the soil. Around 1% of total transpired water being used in the growth process as it transports nutrients from the soil into the roots and carries them to the various cells of the plant and is used to keep tissues from becoming overheated. Certain plants of dried environment do have the ability to open and close their stomata which is to limit the loss of water from plant tissues; otherwise, they will not survive.

Generally, differentiate between evaporation and T is difficult. Hence a composite term "ET" is used whose rate at any instant from the Earth's surface is controlled by four factors: (1) Vapor pressure gradient. (2) Energy availability as about 600 calories of heat energy to change 1 g of liquid water into a water vapor. (3) The wind speed directly above the surface which moves the vapor from the place of evaporation and in clam days when above ground layer got saturated, ET almost stops. (4) Water availability which is a must parameter as at the global scale, most of the ET of water on the Earth's surface occurs in the subtropical oceans where high quantities of solar radiation convert liquid water into a gas. Further, it is reported that average ET for the northern hemisphere is around 944 mm year^{-1} . Together with the southern hemisphere, with an average ET of $1064 \text{ mm year}^{-1}$, this results in a global ET of $1004 \text{ mm year}^{-1}$. In the Western Pacific and the Indian Ocean values up to 2 m year^{-1} have been observed. Thus it varied a lot depending on the special variations.

Evapotranspiration (ET) is an important soil water balance component and is playing a major role in determining the potential yields in the agricultural sector. Being affected by a number of factors, viz. soil temperature, soil moisture and vapor pressure gradients, ET remains almost remains similar for a particular soil textural class and agro-climatic conditions. Regarding estimation of ET, in field conditions, evaporation is generally judged by installing the lysimeters in the field which actually represent the true conditions of the field. Mini-lysimeters were quite effective in understanding the fluctuating behavior of evaporation under different treatments [26, 27]. Mini-lysimeters prepared by using PVC pipes of 8-inch length and with 2.5 inches diameter. Mini-lysimeters were filled from a particular treatment with the help of chain pulley arrangement, an end cap fixed on one side and then finally filled and capped mini-lysimeter was placed inside the outer pipe of the bigger diameter which was already fixed in the sampled plot (**Figure 4**). Daily mini-lysimeters were weighted at field using the digital balance to have an idea of evaporation [29]. After calculating the evaporation T is calculated from the soil water equation where the right-hand side has irrigation and rainfall while left-hand side constituted by seepage, drainage, profile soil moisture and ET.

With this technology, E reduction trends could be very easily monitored because of practiced different resource conservation technologies and thereby for a region the most effective one could also be identified which further be advocated the farmers for improving their livelihoods [30]. Some earlier studies



Figure 4. Demonstrating filling of lysimeters (a); pulling out filled lysimeters with specially designed chain-pulley arrangement (b); and weighting of filled and capped lysimeter (c) [28].

had shown the promising results of some of the technologies, viz. straw mulching caused 70–300 mm of irrigation savings in different crops and benefits of mulching depend upon seasonal rainfall, irrigation regimes and soil texture [31]. These irrigation savings are due to a reduction in soil water evaporation component of ET. However, among the various technologies, zero tillage is emerging as the viable option for planting wheat while retaining surface residues. Earlier there were problems with the direct drilling of wheat seed into combine harvested paddy fields as loose straw accumulates in seed drill furrow openers, seed metering and its placement were non-uniform which is now solved with the Lucky drill directly drilled wheat seeds into anchored and loose rice residues. Major advantages of this technology include about 5–10% increase in yield, 60–70% less weed growth, 30% water saving particularly pre-sowing irrigation and 45 mm reduction in evaporation losses. In spite of these advantages, it solved the problem of straw burning and the leftover paddy straw on the long run improved the soil health and its fertility levels. In the agricultural sector, irrigation efficiency generally is tried to improve by depressing the evaporation share and enhancing the T which further directly linked with the land as well as water productivity.

6. Conclusion

From the above discussion of the chapter, it may be concluded that climate change will adversely affect the sustainable crop production in future that ultimately lead to decrease the food production of increasing population. Different international organizations already projected that water availability in arid and semi-arid regions across the world will decrease, due to lack of rainfall and increase the temperature which leads to increase in the dry areas. Since climate change will impact on soil water balance that leads to change in evaporation and plant transpiration. While, with the increasing temperature, lack of precipitation and soils water unavailability, crop production will likely to decrease through shortening the crop growth cycle. Therefore, it is important to understand evaporation, transpiration as well as evapotranspiration to mitigate their adverse effect under future changing climate. Researchers already revealed that soils with high water holding capacity and crop cultivars which are tolerant to adverse effect as well as the application of improved management strategies will be better to face the impact of drought. Where, if we could increase the irrigated areas, the total crop production could be increased to the food security of increasing population.

Conflicts of interest

The authors declare no conflicts of interest.

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Author details

Rajan Bhatt^{1*} and Akbar Hossain²

1 Regional Research Station, Kapurthala, Punjab Agricultural University, Ludhiana, Punjab, India

2 Bangladesh Wheat and Maize Research Institute, Dinajpur, Bangladesh

*Address all correspondence to: rajansoils@pau.edu

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