Tensiometers for Rice Water Footprints

Rajan Bhatt1*

1Regional Research Station, Kapurthala, Punjab Agricultural University, 141004, Ludhiana, Punjab, India.

Author’s contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/CJAST/2020/v39i3030966

Editor(s):
(1) Dr. Aydin Unay, University of Aydin Adnan Menderes, Turkey.
(2) William Fenner, Mato Grosso State University, Brazil.
(2) Badni Nadia, Centre de Recherche Scientifique et Technique en Analyses Physico-Chimiques (CRAPC), Algeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57015

Received 25 March 2020
Accepted 28 May 2020
Published 29 September 2020

ABSTRACT

Water footprints (WFs) of rice are quite higher viz. 992 billion cubic metres per year (Gm3 yr⁻¹) than from the other cereals which further responsible for the lower water productivity. Out of global WFs for crop production viz. 7404 Gm³ yr⁻¹ corresponds to 78 % green, 12 % blue, and 10 % grey water, respectively. Around 3000-4000 litres of water required for one kg of rice grains and conventional puddle transplanted flood irrigations responsible for this. Therefore, there is an urgent need to cut down rice WFs share. Over irrigated pounded water under conventional puddle transplanted rice responsible for the emissions of the green house gases in atmosphere, which further has its own complications. With time, due to excessive withdrawals of the underground water, the water table is declining at a faster rate and seems to be beyond the reach of the middle class rice farmers. Rice water productivity declining day by day due to huge water demand of rice crop followed by reduced yields. A major share of the applied irrigation water lost/evaporate in the atmosphere. Soil water tension controls the soil moisture dynamics and directly linked to the plant need based approach. Being a kharif crop, rice season faces harsh summers and where evaporative demands of atmosphere intensified to many folds and thus, irrigation water has to be applied frequently. Annually additional water of worth US $ 39 million is withdrawn in NW Indian Punjab state for feeding crops, particularly rice. Tensiometer is the only instrument provided to the rice farmers for applying irrigation water judiciously based on the plant need which further cut down WFs from 18 to 22%. This practise where on one side saves irrigation water, improves declining land as well as water productivity of rice, also controlled the emissions of GHGs from the soil.
1. INTRODUCTION

Water footprints- an indicator generally used for measuring the total amount of volume of fresh water consumed to produce a particular good, or to provide a service. The term coined first by [1] with an objective of assessing the WF of goods and techniques to made food production or goods production more sustainable. Further, WF is a multidimensional indicator delineating water volume consumptions in production and polluted with industrialization specially and temporal. The global water footprint related to crop production in the period 1996–2005 was 7404 billion cubic meters per year (78 % green, 12 % blue, 10 % grey). A large total water footprint was calculated for wheat (1087 Gm³ yr⁻¹), rice (992 Gm³ yr⁻¹) and maize (770 Gm³ yr⁻¹) [2]. Wheat and rice have the largest blue water footprints, together accounting for 45% of the global blue water footprint. At country level, the total water footprint was largest for India (1047 Gm³ yr⁻¹), China (967 Gm³ yr⁻¹) and the USA (826 Gm³ yr⁻¹). A relatively large total blue water footprint as a result of crop production is observed in the Indus river basin (117 Gm³ yr⁻¹) and the Ganges river basin (108 Gm³ yr⁻¹). The two basins together account for 25% of the blue water footprint related to global crop production. Rice being a water guzzling crop with global WF 992 Gm³ yr⁻¹ [3,2] therefore scientists around the region, working to reduce the share of WF for improving water productivities [4,5,6] as it finally helps to practise sustainable agriculture in the water stressed regions. Further around 3000-4000 litres of the water inputs required on an average to produce just 1 kg of the grains. Table 1 clearly delineates the brief calculations of the WFs of rice by assuming 25 irrigations during the crop season while having 30 qt acre-1 of the land.

**Table 1. Calculations of rice water footprints (Bhatt, R Personnel communications, 2020)**

| Step | Calculation | Result |
|------|-------------|--------|
| 1 acre | 4000 sq. m | 1 |
| 1 irrigation | 10 cm = 0.10m | 2.50 |
| 25 irrigation | 250 cm = 2.50m | 6,250 |
| Total water used | 4000 x 2.50 = 10,000 m³ | 10,000 |
| 1 m³ = 1000 ltr | | 10,000,000 |
| 10,000 m³ = 10,000,000 ltr | | |
| 3000 kg paddy = 10,000,000 ltr | | |
| 1 kg paddy = 3333 ltr | | |

Further, global water footprints of rice countries wise delineated in the Fig. 2, which reflects the higher rice water inputs in India as compared to other countries [21].

Therefore, need to change the conventional methods with the advanced methods was required. Number of techniques recommended in the regions particularly suffering or expected to be suffering from water stressed conditions in near future and these techniques are known as resource conservation techniques (RCTs). Among different RCTs, direct seeded rice [14], bed planting, mechanical transplanting [15], laser levelling [22], soil matric potential based irrigation using tensiometers [16,18,19,23] etc being recommended. The tensiometer is in the limelight as it suggested the farmers when to irrigate [24] by measuring soil matric potentials and probably first gadget of its kind [23, 25, 26]. Along with rice, tensiometer found to be effective for wheat water management in Nepal [27]. Further, its readings are not subjective to the temperature

**Keywords:** Water footprints; tensiometer; rice; land productivity; water productivity.
variations, thus could be effectively used in different water stressed regions for reducing the WFs. Routine monitoring of water potentials in rhizosphere is a must for effective irrigation management through tensiometers. Annually additional water of worth US $ 39 million is withdrawn in NW Indian Punjab state for feeding crops particularly rice.

Freshwater competition continuously increased during current years due to a growing population, urbanization, economic growth, changing dietary habits, food wastage etc. [28,29] which further led to problems for future food security and environmental sustainability [30]. As per National Aeronautics and Space Administration (NASA), USA the underground water levels declined down and experience changes both on the temporal and special basis from 2005 to 2020, because of huge WFs (Fig. 4). Further, figure clearly delineated the conditions in the NW India viz. Punjab, Haryana known as food bowl of India are also not an exception and facing the water stress, which happens for the intensively cultivated rice based cropping systems in the region. Therefore, there is urgent need to cut the water fronts, for which tensiometer must be used by the paddy farmers of the region.

2. Tensiometer Principle and Working

Energy status of the soil solutions, which referred to as “soil matric potential” (SMP), measured by tensiometer (Soil Science Society of America, SSSA 1997) as moisture moves in the direction of decreasing potentials. As per definition, SMP is the amount of work that must be done per unit of a specified quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a specified source to a specified destination [31] SMP further referred as soil water tension (SWT).

The availability of moisture to the plants is the function of the textural class of the soils as coarser the texture of soils, higher the sand percentage and higher the availability of soil moisture than the fine textured soils. Soil moisture held within the soil matrix with soil matric potential. In any crop, irrigation interval duration depends on the evaporative demand of atmosphere, textural class of soils and adopted cultural practices. SMP is the index which helps to delineates the soil moisture status in relation to atmospheric evaporativity and soil texture [32]. Generally in the irrigation experiments, irrigations scheduled on the basis of SMP of 20 kPa at 20 cm depth in rice [33] and 35 kPa at 35 cm in wheat [34] using electronic tensiometers installed in each plot at differential depths viz., for wheat at 10, 20, 30, 45, 60 and 90 cm while for rice 10, 15, 30, 45 and 60 cm soil depths respectively (Fig. 5).

Tensiometers consist of three basic components viz. porous cup, acrylic pipes inner of small diameter fixed with the ceramic cup while the

Fig. 1. Deepening of the bores of the tubewells because of declined underground water table
Fig. 2. Global rice water footprints including internal, external and total water footprints (Mm3 Year\(^{-1}\)) Source: [19,2]

Fig. 3. World cereal production targets and global non-CO2 greenhouse gas (GHG) emissions by agriculture sector [11]

http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html
Fig. 4. Temporal changes in Global ground water trends from 2005 to 2020
(Compiled by Bhatt. R Source: https://nasagrace.ul.edu/Slider.aspx)

Fig. 5. View of installed tensiometers of differential lengths in rice (A,B) and wheat (C,D)
Source: [34]
outer pipe is of larger diameter fitted with a silicon cork and has three coloured strips viz. of green, yellow and red. Tensiometer cups, behaves like a permeable membranes at the soil water interphase. Tensiometer delineates how forcefully moisture is detainted to particles of soil as higher the tension values more is the need for irrigation. Further, light textured soil attained high tension values quickly than heavy textured soils as former soils not able to hold water for a longer period of time and thus drain it quickly than the later heavy textured soils. Generally, pores are quite bigger as pore size for a flow ceramic cup of 1 bar is 2.5 μm which is approximately 6000 times larger than a hydrated Na molecule [35]. Selection of the porous cup depends on the cup conductance, K which is delineated as

\[ k = \frac{V}{T \Delta H} \]

where V is the volume of water that flows through the cup in time T when a hydraulic head difference \( \Delta H \) is applied [36]. Further, bubbling pressure is the pressure difference required to force a gas phase through a wetted porous cup [36] and is dependent on the radius of the largest continuous pore in the porous cup and the surface tension of the water in the tensiometer. The gauge which sometimes not worked due to different reasons, replaced by Punjab Agricultural University, Ludhiana, Punjab, India with three coloured strips viz. green, yellow and red strips for the ease of the farmers (http://cipt.in/publications/pdf/Discussion_Paper_Tensiometer.pdf) on the outer PVC pipe [37]. For getting energy equilibrium, water moved in or out of the porous cup in the inner pipe and its water levels monitored on the outer tube strips. If water levels in the inner PVC tube is in green coloured strip, then no need to irrigate (Fig. 6). However, if water level enters from green strip to the yellow strip, then there is a need for the irrigation and under no conditions, water levels should be allowed to enter in the red strip, as there soil gets cracks and hence, certainly resulting in yields reductions which is not required at all [32].

Overburden pressure could also affect the tensiometers readings, but mostly ignored during calculation parts of soil matric potentials. Quite often, tensiometers installed vertically in irrigation experiments, but could also works in horizontal direction in trench walls [38,39] for monitoring of the soil moisture dynamics at differential depths.

3. WORKING STEPS OF TENSIOMETERS

3.1 Before Installation

Tensiometer ceramic cup saturated with water overnight by keeping them in the half water filled bucket. Both tubes and the cup filled with distilled or boiled and the cooled water. This operation needs regular tapping as filling water in the inner PVC tube is not so easy. Mostly farmers even used injection syringes for this purpose. The water in the inner tube tries to come in equilibrium with the surrounding water through the porous ceramic cup as a result inner tube water levels fluctuates as per soil water contents. Afterwards, the tensiometers brought to the field for their actual installation within that very bucket, otherwise air may enter.

3.2 During Installation

After nursery transplantation, for the first fortnight flooded conditions maintained and

Fig. 6. Tensiometer recommended for the rice farmers Source: [36]
thereafter when all the standing water infiltrates and at field capacity conditions, bigger hole than of the outer PVC made upto the rhizosphere i.e upto 20cm depth. Afterwards, tensiometer inserted in the hole and sealed with the mud prepared from soil and water in the ration of 1:2. While sealing, regular sticking required assuring the air tight conditions, followed by refilling of water in the inner tube. Lastly, cork used to plug the tensiometer which breaks its air contact and then the system is isolated and fully functional. If water level immediately falls down then it means that the tensiometer is broken and there is need to replace it. Plugging cork is made up from the silicon which resists to any expansion even at temperature beyond 38-40°C. Irrigation is recommended when inner PVC tube water level touches the bottom of the green strip and just going to enter in the yellow strip. After irrigation, water level will again rise in the green strip. Tensiometer’s suction readings should preferably be monitored during the morning hours.

3.3 After Crop Maturation

As and when the rice crop matures, then there is no need for the irrigation further. Hence it is advisable to remove the tensiometers around 7-10 days before proposed harvesting. After removing them, the tensiometer should be washed with the diluted acidic solution to get rid off from the salts, so that it could be reused in the next rice crop for sustainable use of the irrigation water and to reduce the water footprints.

4. SOIL WATER MOVEMENT

From soil water movement, total soil water potential which includes matric, gravitational, osmotic and gas potential, out of which matric potential along with gravitational potential are the most important one [40,41]. Generally, in agricultural water management experiments, for rabi season viz. wheat first common irrigation applied to all the plots after four weeks of sowing viz. 28 days after sowing. Differential irrigations applied to differently treated plots based on 35 cm tensiometers with soil matric potential of -35 kPa. Final irrigation provided just two weeks prior to wheat harvesting. In rice crop, ponded water conditions maintained till two weeks after transplanting and thereafter, irrigation provided at potential value of -15 kPa with the help of 15-20 cm depth installed tensiometers [32].

5. SMP MEASUREMENT DURING INTERVENING PERIODS

For the first time SMP measured globally, during the intervening periods of rice-wheat cropping sequence using tensiometers [33,39]. During intervening period after wheat harvesting before rice transplanting, zero-till wheat plots dried faster compared to the conventionally tilled wheat plots during both in 2013 and 2014, which

Fig. 7. Soil matric potential as affected by tillage treatments during the intervening period between wheat and rice at (a) 10 cm, (b) 20 cm and (c) 30 soil depths (Source [34])
might be because of removal of crop residues. The drying was higher (28 percent) in 10 cm soil layer (Fig. 7a) than in 20 and 30 cm (18 percent) layers during 2013 (Fig. 7b, 7c). The corresponding values during 2014 were 21 percent at 10 cm soil depth (Fig. 8a) compared to 16-17 percent in lower soil layers (Fig. 8b, 8c) [39].

In general, the zero tilled plots (without straw load) had higher soil temperature, soil matric potential, higher evaporation losses during the intervening periods after wheat harvest.

6. Tensiometer Performance

Tensiometer could be used for the different purposes as

6.1 For Improving Water Productivity and Power Saving

Carried out research revealed that tensiometer based irrigation scheduling saved significant water quantities along with potential land productivity. During the year 2006, the considerable amount of water was saved with a mean value of 30.2% with non-significant crop yields (Fig 9a). However, from the year 2007 to 2010, tensiometer based total water saving varies from 26.1, 22.9, 18.7 and 16.25, respectively with non-significant yields [16,42]. An enhancement of 75.8 % in water savings with soil matric potential approach in comparison to famous open irrigation in puddle transplanted rice [42,43] (Fig 9b).

Tensiometers helped in saving of significant amounts of the irrigation water and thereby reducing water footprints in the crops without affecting the yield potentials of the crops (which could be used in other relevant sectors) [Vitta et al., 43] and the energy/power to extract it from underground [42] On a range, tensiometers brought downwards the WFs in rice crop to 14-15 percent could be further linked with the saving of power, which otherwise used to withdraw water from deeper depths [42].
6.2 For Irrigation Scheduling

Tensiometers improved the land as well as water productivity by scheduling the plant need based irrigations. Tensiometer set a marked point beyond which yield reductions are there and therefore, farmers are guided to irrigate their fields before that suction [44]. In wheat, during 2012-13, SMP measured at 10 cm soil depth from 40 days after sowing (DAS) onwards was similar in both CTW and ZTW till 50 DAS (Fig. 10A). After this, the CTW plots started drying at faster rate as compared to zero-till plots till harvest. At 20 cm soil depth, the SMP till 63 DAS and thereafter indicates that the zero till plots retained higher moisture than the CTW plots (Fig. 10A). From 78-119 DAS, the moisture status in the two tillage systems was similar, but thereafter, CT plots dried at a faster rate. At 30 and 45 cm soil depth during 2012-13, the SMP was similar in the two treatments whereas at 60 cm, the CTW plots behaving similarly to ZTW plots till 78 DAS, dried at a faster rate thereafter (Fig. 10A) [33].

Interestingly at 90 cm soil depth, the CT plots were dried faster than ZTW plots throughout the growing season. These fluctuations in SMP during 2012-13 at different soil depths indicate that zero tillage affected both the upward as well as downward movement of oil water into the soil. The continuity of capillaries in zero-till plots could have resulted in upward movement of water into surface layer of plots [34]. The presence of rice straw @ 4.4 t ha$^{-1}$ could be another reason for the higher wetness of the zero-till plots (Fig. 10C). Balwinder Singh et al (2011b) in clay loam soil reported that in irrigated wheat, mulch suppressed whole season soil evaporation by 35-40 mm and resulted in higher wetness in mulched plots as compared to the unmulched plots. Similar type of observations were made with respect to SMP at different soil depth during 2013-14 except that at 90 cm the wetness of soil in all the tillage scanarios was almost similar unlike as in 2012-13 (Fig. 10C).

In rice, SMP profiles at different depths (Fig. 10B), during 2013 and 2014 (Fig. 10D) indicate that the zero till plots dried at a faster pace in the surface layer (10 cm) The SMP did not vary much with respect to different tillage scenarios in the sub-surface layers (15-60 cm) (Fig. 10B) due to frequent irrigations to DSR plots. However, during initial stages (43-51 DAS), double zero till plots had lowest moisture status among all the tillage scenarios except CTW-DSRCT plots in which the moisture status was similar to that in double zero till plots. Similar trend was observed in soil matric potential recorded at different depths during 2014 (Fig10D). The zero till plots are expected to dry at a faster rate due to continuity of soil pores in these plots [33]. This is evidenced from the evaporation measured during the rice season, which was sufficiently higher (36 per cent in 2013 and 22 per cent in 2014) in complete zero till system than in conventional system of tillage in DSR plots [33].
Fig. 10. Tensiometer readings in wheat at different soil depth in relation to CT and ZT plots in wheat during 2012-13 [A] and 2013-14 [C] and in rice at different soil depths during 2013 [B] and 2014 [D]under different establishment methods viz, direct seeded rice and mechanical transplanting under puddled, conventionally and zero tilled conditions at sandy-loam soils of semi-arid tropics [33]

Some recent studies have been conducted with tensiometer systems connected, via data loggers and/or computers, to solenoids and water pumps, to improve water productivity. For instance, a series of tensiometer nests used to study the micro-sprinklers for irrigating almond trees and thus adjusting irrigations as per plants need [45,44]. Further, in wheat, Al-Amoud and Mohammad [46] reported to had water productivity improvements upto 24 to 27%. Further, [47] developed a control valve that automatically opens and closes depending on the matric potential of the soil water as when potential decreases, a piston was pulled inward, opening the irrigation outlet while under reverse conditions piston closed, which stops irrigation. Tensiometers evaluation for root water movement done by many scientists with time as [48] (in flowering plants), [49] (in corn (Zea mays L.), [50] (in potato (Solanum tuberosum L.), [38] (in rice-wheat cropping sequence) and [51] (in almond trees). Hence, tensiometers could be used for irrigation scheduling and improving both land as well as water productivity of the crops more particularly grown under water stressed conditions.

6.3 For Delineating Unsaturated Hydraulic Conductivity

Tensiometers widely used for determining soil hydraulic properties [52,53,54] Bhatt and Kukal
[33,39] conducted experiments under semiarid tropics for scheduling irrigation using tensiometers in both rice as well as in the wheat crop for evaluating the performance of the recommended resource conservation technologies in the region. Tensiometers installed at different depths and used for scheduling irrigation as per soil moisture potentials. However, some scientists used rapid-response tensiometers to notice variations in the wetting fronts [53,54] so that highly transient flow behavior in soils could be observed and quantified. Tensiometer measurements used for estimating the soil hydraulic properties for the entire soil profile. Wang et al. [55], Vandervaere et al. [56], and Timlin et al. [57] estimated the soil hydraulic properties from the tensiometer data regarding soil water matric potential from a single field experiment.

6.4 For Estimating Recharge

Under field conditions, tensiometers helps in delineating the recharge status [58,59]. Prior scientists under sandy soil at a semiarid site in New Mexico used tensiometers at several depths. Further, their tensiometers equipped with mercury manometers, however, it replaced with hand-held pressure sensor, the Tensiometer. Further, and they estimated unsaturated hydraulic conductivities using the instantaneous profile method. In other experiments at a semi-arid conditions of New Mexico, ambient recharge took place with a bare soil surface [59,60]. Therefore, tensiometers could be used for estimating the recharge of ground water.

6.5 For Monitoring of Contaminant Transport

Tensiometers further could be used for delineating the contaminant movement in the sewage treatment plants as it measured the changes in soil water matric potential. Hubbell and Sisson, [61] measured the water potential changes resulting from snow melt events upto 50 ft in a fractured basalt. Further, Nyhan and Drennon [61] used tensiometers for movement of moisture through landfill covers. Further, used pressure transducers to measure the soil water matric potential [61,62]. Therefore, tensiometers also help to monitor the transport of contaminants.

6.6 For Measuring Drainage

Percolation is an important factor controlling the transport of nitrate [63,64,65] heavy metals [65, 66], salts [67] and pesticides [68,69] to groundwater and for reducing the applied water footprint of rice production [2,70,71,72]. Tensiometers could be used for measuring the drainage losses and for it, electronic tensiometers installed at 450 and 600 mm assuming rhizosphere up to 500 mm [54,59]. For drainage a calculation, unsaturated hydraulic conductivity needs to be delineated by using disk permeameter is used throughout the soil profile. Now, for calculating the flux using Darcy’s law (equation 6), delineation of the unsaturated K of the transitional layer on a daily basis is very important which further expressed as deep drainage.

\[ q = \frac{K \cdot \Delta H}{L} \]

Where \( Q \): Flux; \( K \): Unsaturated hydraulic conductivity; \( \Delta H/L \): Hydraulic gradient. Further, Hydraulic gradient (\( \Delta H/L \)) changed to the suction gradient (\( \Delta \Psi t/L \)), for tensiometers

\[ q = \frac{K \cdot \Delta \Psi t}{L} \]

\( \Psi t \) is total potential which is sum of matric and gravitational potentials viz. \( \Psi m + \Psi g \) [62]. Disk permeameter generally used for estimating unsaturated hydraulic conductivity values upto 0-150 cm. For estimating water drained deep through the soil profile equation 4 is used.

\[ q = \frac{K \cdot \Delta \Psi /L}{L} \]

\[ q = \frac{K \cdot \Delta \Psi A - \Delta \Psi B}{L} \]

Generally, the tensiometer reading is in kPa but for the soil water balance studies readings in “cm” are necessary which converted by multiplying kPa reading with 10. After filling reading in above equation, flux (q)/drainage (D) loss in different plots could be easily delineated.

Instead of it, tensiometer also used for managing the implications of the Frost heaving i.e upward swelling of the soil during freezing conditions caused by an increasing presence of ice [73] as it known that frost heave was due to the freezing of migrated water to the freezing front instead of freezing of in situ water. Further, tensiometer based scheduling of irrigation also recently
reported to hike the water use efficiency and yields in the strawberry [74]. In wheat, generally, drainage losses assumed to be negligible or near to 100 mm while in the rice season drainage losses are of significance (>2000 mm).

7. FACTORS IDENTIFIED FOR LOWER ADOPTIONS

Instead of a number of benefits of tensiometers, the adoption rate among the farmers of the water stressed region is not upto the satisfactory levels and a number of factors both direct as well as indirect responsible for poor adoption rate of the tensiometers for irrigation scheduling in the region are (Rajan Bhatt, Personnel communications, 2020)

7.1 Direct Factors

7.1.1 Farmers offered with free power supply, hence they don’t bother about the water footprnis of the crops, particularly rice and generally applied flood irrigations.

7.1.2 Farmers are not willing to pay to purchase the “Tensiometers” as they assumed it as extra burden which they have to made from their pocket for saving water which is free. Paying to save something which is already free not attract them.

7.1.3 Tensiometers need to be saturated overnight before their installation in the field. Filling the water in the inner PVC tube is really difficult and complex operation that needs frequent tapings in between. This operation is not easy for the farmers and they feel it difficult.

7.1.4 Tensiometer installation is also a technical operation as it is to be installed in the rhizosphere at about 6” depth with a pipe having diameter wider then tensiometer. Further, after inserting tensiometer at proper depths, gap is to be filled with the mud (made from soil and water) with an objective to create air tight conditions. This is not easy job for the farmers.

7.1.5 If tensiometers get cracked in the way from his house/motor to field, even then it loose its operation of measuring the suction. Being unaware of cracking, farmers fit this cracked tensiometers and not getting the water levels reading in strips, which really frustrate them as they need to replace it with fresh one with extra costs.

7.1.6 Most of times, there is no power, when water levels of inner pipe is in the yellow strip, which dictates for irrigation. If this conditions, prevails longer, then water could enters in the red strip which further resulted in soil surface cracking and a reduction in yields. Hence, under free power conditions, he installed automatic switches which get on automatically with power supply for irrigation application.

7.1.7 Under paddy combine harvesting, mostly installed tensiometers get broken, which is a loss and farmers are not willing to re-purchase it with extra costs.

7.1.8 Even if farmers remove it before harvesting, even then washing it with diluted solutions for removing salts from the porous cup is not easy job.

7.1.9 Keeping the tensiometer from October to June idle in the motor corners with care is not easy. Moreover reinstalling them during next paddy season is also forgotten due to busy schedule. Further, if farmers offered their land on lease, then their interest to save water is no more.

7.2 Indirect Factors

Instead of direct factors there are some other hidden indirect factors which also played an important role in deciding the adoption rates of the tensiometer for reducing the water footprint of rice.

7.2.1 Risk bearing ability of the farmers

This is the main factor which decides the adoption rate of the farmers for the adption of the tensiometers, as most of farmers could not be willing to divert from the old lines viz. flood irrigations.

7.2.2 Income year

It is an important factor which decides the adoption rate by the farmers. If a farmer having good income due to any reason (might his children settled in abroad or having heavy wealth of his fore-fathers), he is able to take risks and could be mould his irrigations based on schedule. Generally, only rich farmers could bear risks and eager to have his name in the newspapers/mass media etc. while poor farmers even willing not able to bear risks.
7.2.3 Mass media exposure

Mass media viz. news paper, TV or radio has an important role in awaring the farmers regarding role of tensiometers, their availability and their rates and its mode of action. Further, under the present scenario of COVID-19, role of media increased to manifolds for bringing awareness in between the farmers. Generally farmers adopting tensiometer are under the frequent contact with these mass media.

7.2.3 Land holdings

Big farmers with higher land holding commonly are the first to adopt new techniques viz. tensiometer based irrigations. Further, they have as easy access to the different governmental organizations viz. bank or cooperative societies than the farmers with smaller land holdings. However, farmers with big land holdings generally be selected by the different government agencies because of their risk bearing ability.

7.2.4 Education status

Education is the main factor towards the awareness as illiterate farmers remained in his circle and not willing to adopt new methods of irrigations. Further, family size is also another factor affecting the adoption. In Punjab, new generation flying to European countries and older ones remained back, which have almost nil interest in adopting the new techniques viz. tensiometers. Mostly, for meeting their children foreign requirement they sell their agricultural lands near the roadsides for construction of malls, marriage palaces or colonies. Under this scenario, adoption rate of tensiometers still in question.

7.2.5 Extension officer’s visits

Responsibility of the extension officer is to familiar the farmers with the tensiometers based irrigations by demonstrating them at their fields as mostly farmers believe on watching at their fields. But limited staff of extension officers might not able to visit all the farmers. Therefore, visits of the extension scientists known as Subject Matter Specialist particularly of the soil science is very important for clearing all the doubts of the farmers.

7.2.6 Participation in farmers fairs/ Kisan Melas

This is also an important factor regarding adoption of new technologies propagated for the sustainable agriculture as tensiometer is not an exception. Mostly state agricultural universities are organizing the farmer’s as Punjab Agricultural University, Ludhiana, Punjab, India organizing two state level fairs known as “KISAN MELA” where thousands of farmers not only from the state but also from the neighbouring states visited for the purchase of new seeds and to get knowledge regarding new RCTs viz. tensiometers. Therefore regular visitors could easily understand the concept and adopt tensiometers for irrigating the tensiometers.

7.2.7 Farming experience

Experience is the most important factor for deciding the adoption rate of new agricultural technologies and afterwards they becomes the torch bearer for the rest of the farmers of the village.

7.2.8 Links with agricultural extension centres

Most of the South Asian countries have their extension centres for the farmers. Punjab Agricultural University, Punjab, India also set up extension centres at the district levels known as “KRISHI VIGYAN KENDRAs” which itself acts as a mini university and farmers which could not afford or which has limited time, get the almost same benefits from these KVKs. Farmers which use to visit KVKs, obviously well known with the latest RCTs viz. tensiometers than from the farmers which use not to visit KVK frequently. Moreover, KVK staff also gets the contact number of frequently visiting farmers and inform them in case of any opportunity offered by the government from time to time. Hence, adoption rate of tensiometers will certainly depends upon the farmer’s visits to the KVKs.

7.2.9 Innovation proneness

Some farmers are of innovative nature and they used to test technology as they knew about them without caring for the risks. Such farmers quite easily adopt the new technologies. Such farmers through their experience will guide the others in the next year that which RCT will work under which conditions and thereby further improves the rate of adoption of the tensiometers for cutting the water footprints in rice.

8. CONCLUSIONS

Water footprints of rice are globally very high and conventional establishment methods of rice viz.
puddled and irrigation methods viz. flooded further responsible for this which led to water discrepancies. Further, ever increasing population and target to produce more and more grains from shrinking resources seems to be a difficult. Among resource conservation techniques (RCTs), “Tensiometer” holds a special place as it guides when to irrigate. However, adoption rate is not upto the mark, which might be because of several direct and indirect factors. Further, free power supply for tube wells is the biggest hurdle. However, government must frame some policies in this regard. WFs of rice must be reduced with desired yields by any means in the water stressed regions which afterwards be diverted and then used to the other sectors viz. industrialization, urbanization, house-holds etc. Some factors identified for the adoption of the tensiometers below expectations involving both direct and indirect ones, which needs to addressed as soon as possible through the integrated approach which further supported by the government policies. Further, different awards/incentives might be constituted by state government/NGOs/universities for farmers, who applied irrigation water as per tensiometers readings to mitigating the adverse effects of the global warming. Therefore, tensiometers must be popularized after delineating their role in reducing global rice water footprints, more particularly in the water stressed regions under climate change scenario.

ACKNOWLEDGEMENT

Author acknowledges scientists across the globe, who share their publications required while compiling this review.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Hoekstra A Y, Hung P Q. ‘Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade’, Value of Water Research Report Series No 11, UNESCO-IHE, Delft, Netherlands, 2002; www.waterfootprint.org/Reports/Report11.pdf
2. Mekonnen MM, Hoekstra AY. 2011. The green, blue and grey water footprint of crops and derived crop products. Hydrol. Earth Syst. Sci. 2011;15: 1577–1600.
3. Bhatt R, Hossain A, Singh P. Scientific interventions to improve land and water productivity for climate smart agriculture in South-Asia. Agronomic crops., 2020a; (2): 499-558. https://doi.org/10.1007/978-981-32-9783-8
4. McKinsey. Pathways to a Low-carbon Economy: Version 2 of the Global 755 Greenhouse Gas Abatement Cost Curve. Technical Report, 2009; McKinsey & 756 Company
5. Bhatt R, Hossain A, Hasanuzzaman M. Adaptation Strategies to Mitigate the Evapotranspiration for Sustainable Crop Production: A Perspective of Rice-Wheat Cropping System. Agronomic crops. 2020b; (2): 559-582. https://doi.org/10.1007/978-981-32-9783-8
6. Bhatt R, Kaur R, Gosh A. Strategies to practice climate smart agriculture to improve the livelihoods under rice-wheat systems in South Asia. Sustainable Soil and Environmental Management. 2019; 29-72. https://doi.org/10.1007/978-981-13-8832-3_2
7. IFA.International Fertilizer Association, Paris (France). 2019; IFASTAT, https://www.ifastat.org/databases/plant-nutrition
8. Russenes AL,Korsaeth, K, Bakken LR, Dorsch P. Effects of nitrogen split application on seasonal N2O emissions in South East Norway. Nutr Cycl Agroeco. 2019; 115:41-56.
9. Bruinsma J. World agriculture: towards 2015/2030, an FAO perspective. 2003 Rome, Italy: Earthscan, FAO
10. Wheeler TR, Braun JV. Climate change impacts on global food security. Science. 2013; 415:508–513. doi:10.1126/science.1239402
11. Wu W, Ma BL. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Sci of Total Environ. 2015; 512: 415–427 doi:10.1016/j.scitotenv.2014.12.101.
12. Lal, R. Soils and sustainable agriculture. A review. Agron. Sustain. Dev. 2008; 28: 57-64.
13. FAO. Food and agriculture organization of United Nations. 2020. http://www.fao.org/faostat
14. Bhatt R, Kukal SS. Direct seeded rice in South Asia. in: Eric Lightfouse (ed.)
Sustainable Agriculture Reviews, 2015; 18: 217-252.

15. Bhatt R, Kukal SS, Arora S, Yadav M. Comparative performance of mechanical transplanter in South-Asia. J. Soil and Water Conserv. 2014; 13(4): 388-394.

16. Bhatt R, Sharma M. Management of irrigation water through Tensiometer in paddy-A case study in the Kapurthala District of Punjab. In Proceedings of Regional workshop on Water availability and Management in Punjab organized at Panjab University, Chandigarh. 2010, pp 199-205.

17. Bhatt R, Kukal SS, Arora S, Busari MA, Yadav M. Sustainability issues on rice-wheat cropping system. International J Soil and Water Conser Res. 2016; 4: 68-83. DOI.org/10.1016/j.jswcr.2015.12.001

18. Marthaler HP, Vogelsanger W, Richard F, Wierenga PJ. A pressure sensor for field tensiometers. Soil Sci. Soc. Am. J. 1983; 47:624–627.

19. Chapagain A. Water footprint of rice-Quantifying the rainbow of virtual water fluxes related to rice trade. In Rethinking paradigms: Water and Food security. 4th Marcelino foundation water workshop Santander (Spain). 22-24th Sep. 2009

20. Bhatt R, Meena RS. Delineation of Soil Moisture Potentials and Balance Components IN Soil Moisture Importance. 2020; Accepted. ISBN 978-1-83968-096-0. Publisher INTECH open, England

21. Bhatt R, Kukal SS. Direct seeded rice in South Asia. In: Eric Lichtfouse (ed.) Sustainable Agriculture Reviews, 2015; 18: 217-252.

22. Bhatt, R. and Sharma, M. Laser leveller for precision land levelling for judicious use of water in Punjab, Extension Bulletin. 2009; Krishi Vigyan Kendra, Kapurthala, Punjab Agricultural University, Ludhiana.

23. Bhatt R, Arora S, Chew CC. Improving irrigation water productivity using Tensiometers. J Soil Water Conser. 2016; 15 (2): 120-124

24. Bhatt R, Kukal SS. Delineating soil moisture dynamics as affected by tillage in wheat, rice and establishment methods during intervening period. J. Applied and Natural Sci. 2015a; 7(1): 364-368.

25. Kukal SS, Bhatt R, Gupta N and Singh MC. Effect of crop establishment methods on rice (oryza sativa) performance and irrigation water productivity in sandy-loam soil. Agric. Res. J. P.A.U., Ludhiana. 2014; 51 (3&4): 326-328

26. Bhatt R, Kukal SS. Crop performance and irrigation water productivity of rice (Oryza sativa) in relation to divergent establishment methods. In Proceedings of International Conference on “Crop Productivity and Sustainability - Shaping the Future” at Baba Farod group of Institutes, Bathinda. 2014; pp 152-154.

27. Yadav M, Tripathi J, Bhatt R, Rawal N. Tensiometer based irrigation scheduling in wheat for improved water use efficiency in Nepal. J Soil Water Conser. 2018; 17(3). 275-279. DOI: 10.5958/2455-7145.2018.00040.1

28. Shen JP, Zhang LM, Di HJ, He JZ. A review of ammonia-oxidizing bacteria and archaea in Chinese soils. Frontiers Microbio. 2012; 3: 296-312.

29. Strzepek K, Boehlert B. Competition for water for the food system Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 2010; 365 (1554): 2927-2940

30. Rosegrant MW, Cai X, Cline SA. Global water outlook to 2025 International Food Policy Research Institute, Washington, D.C., USA (2002)

31. SSSA. Soil Science Society of America. Glossary of soil science terms. SSSA, Madison, WI.1997

32. Kukal SS, Kahlon MS, Bhatti DS. Alternate wetting and drying in rice-Tensiometer based irrigation scheduling. 2014; Department of Soil Science, Punjab Agricultural University, Ludhiana Extension Bulletin no. 2014/02.

33. Bhatt R. soil water dynamics and water productivity of rice-wheat system under different establishment methods. Ph. D Dissertation.2015; Submitted to Punjab Agricultural University.

34. Weast RC. Handbook of chemistry and physics. 1987; 67th ed. CRC Press, Inc. Boca Raton, FL.

35. Cassel DK, Klute A. Water potential: Tensiometry. p. 563–596. In A. Klute (ed.) Methods of soil analysis. 1986; Part 1. 2nd ed. SSSA Book Ser. 5. ASA and SSSA, Madison, WI.

36. PAU. Package of practices for the crops of Punjab, India. 2020 https://www.pau.edu/content/pfp/pp_kharif.pdf

37. Vinson J, Wierenga PJ, Hills RG, Young MH. Flow and transport at the Las Cruces trench site: Experiment 2b. 1997;
48. Hansen RC, Pasian CC. Using tensiometers for precision microirrigation of container-grown roses. Appl. Eng. Agric. 1999; 15:483–490.

49. Darusman KAH, Stone LR, Lamm FR. Water flux below the root zone vs. drip-line spacing in drip-irrigated corn. Soil Sci. Soc. Am. J. 1997; 61:1755–1760.

50. Shae JB, Steele DD, Gregor BL. Irrigation scheduling methods for potatoes in the northern great plains. Trans. ASAE. 1999; 42:351–360.

51. Andreu L, Hopmans JW, Schwankl LJ. Spatial and temporal distribution of soil water balance for a drip-irrigated almond tree. Agric. Water Manage. 1997; 35:123–146.

52. Wierenga PJ, Hills RG, Hudson DB. The Las Cruces Trench site: characterization, experimental results, and one-dimensional flow predictions. Water Resour. Res. 1991; 27: 2695–2705.

53. Liu Y, Steenhuis TS, Parlanges JY. Formation and persistence of fingered flow fields in coarse grained soils under different moisture contents. J. Hydrol. 1994; 159:187–195.

54. Zou ZY, Young MH, Li Z, Wierenga, PJ. Estimation of unsaturated hydraulic properties from a deep infiltration experiment. J. Hydrol. 2001; 242:26–42.

55. Wang D, Yates SR, Ernst FF. Determining soil hydraulic properties using tension infiltrometers, time domain reflectometry, and tensiometers. Soil Sci. Soc. Am. J. 1998; 62:318–325.

56. Vandervaere JP, Peugeot C, Vaucin M, Jaramillo RA, Lebel T. Estimating hydraulic conductivity of crusted soils using disc infiltrometers and minitensiometers. J. Hydrol. 1997; 189:203–223.

57. Timlin DJ, Ahuja LR, Ankeny MD. Comparison of three field methods to characterize apparent macropore conductivity. Soil Sci. Soc. Am. J. 1994; 58:278–284.

58. Stephens DB, Knowlton R. Soil water movement and recharge through sand at a semiarid site in New Mexico. Water Resour. Res. 1986; 22:881–889.

59. Gee GW, Wierenga PJ, Andraski BJ, Young MH, Fayer MJ, Rockhold ML. Variations in water balance and recharge at three western desert sites. Soil Sci. Soc. Am. J. 1994; 58:63–72.

60. Hubbell JM, Sisson JB. Advanced tensiometer for shallow or deep soil water potential. Soil Sci. 1998; 163:271–277.

38. Young MH, Wierenga PJ, Warrick AW, Hofmann LL, Musil SA, Yao M, Mai C, Scanlon BR. Results of field studies at the Maricopa Environmental Monitoring Site, Arizona. NUREG/CR-5694. 1999. U.S. Nuclear Regulatory Commission, Washington, DC.

39. Bhatt R, Kukal SS. Delineation of soil water balance in wheat-dry direct seeded rice system under conventional and zero-till conditions in semi-arid Tropics. Oryza 2018; 55(4): 574-589. DOI 10.5958/2249-5266.2018.00074.7

40. Bhatt R, Meena RS. Delineation of Soil Moisture Potentials and Balance Components / Soil Moisture Importance. 2020; [Online First], IntechOpen, DOI: 10.5772/intechopen.92587. Available from: https://www.intechopen.com/online-first/delineation-of-soil-moisture-potentials-and-moisture-balance-components. ISBN 978-1-83968-096-0

41. Kukal SS, Hira GS, Sidhu AS. Soil matric potential-based irrigation scheduling to rice (Oryza sativa). Irrig Sci., 2005; 23: 153-159.

42. Vitta K, Sidhu RS, Kaur B. Towards sustainable water and energy use in agriculture: the case of tensiometers in rice cultivation. Technical Report. 2014; 1-12.

43. Campbell GS, Campbell MD. Irrigation scheduling using soil moisture measurements: Theory and practice. In D. Hillel (ed.) Advances in irrigation. 1982; 1: Academic Press, Boca Raton, FL.

44. Koumanov KS, Hopmans JW, Schwankl LJ, Andreu L, Tuli A. Application efficiency of micro-sprinkler irrigation of almond trees. Agric. Water Manage. 1997; 34:247–263.

45. Smajstrla AG, Locascio SJ. Tensiometer-controlled, drip-irrigation scheduling of tomato. Appl. Agric. Agric. 1996; 12: 315–319.

46. Al-Amoud AI, Mohammad FS. Automatic irrigation scheduling by remote controlled tensiometers under arid climatic conditions. Int. Agric. Eng. J. 1995; 4(3):131–145.

47. Peterson DL, Glenn DM, Wolford SD. Tensiometer-irrigation control valve. Appl. Eng. Agric. 1993; 9:293–297.
61. Nyhan JW, Drennon BJ. Tensiometer data acquisition system for hydrologic studies requiring high temporal resolution. Soil Sci. Soc. Am. J. 1990; 54:293–296.
62. Marthaler HP, Vogelsanger W, Richard F, Wierenga PJ. A pressure sensor for field tensiometers. Soil Sci. Soc. Am. J. 1983; 47:624–627.
63. Li Y, Šimůnek J, Wang S, Yuan J, Zhang W. Modeling of soil water regime and water balance in a transplanted rice field experiment with reduced irrigation. Water. 2017; 9: 248. https://doi.org/10.3390/w9040248
64. Maria CDS, Rienzner M, Facchi A, Chiaradia EA, Romani M, Gandolfi C. Water balance implications of switching from continuous submergence to flush irrigation in a rice-growing district. Agric. Water Manag. 2016; 171: 108–119. https://doi.org/10.1016/J.AGWAT.2016.03.018
65. Carrijo DR, Li C, Parikh SJ, Linquist BA. Irrigation management for arsenic mitigation in rice grain: Timing and severity of a single soil drying. Sci. Total Environ. 2019; 649:300–307. https://doi.org/10.1016/j.scitotenv.2018.08.216
66. Ahmad MUD, Bastiaanssen WGM, Feddes RA. Sustainable use of groundwater for irrigation: A numerical analysis of the subsoil water fluxes. Irrig. Drain. 2002; 51: 227–241. https://doi.org/10.1002/ird.59
67. Yada S, Arao T, Kawasaki A, Saito T, Nagai, Man M, Hamada Y. Natural cadmium loading and balance in a non-polluted rice paddy field in Japan. Water Sci. Technol. 2008; 58: 2243–2249. https://doi.org/10.2166/wst.2008.571
68. Watanabe H, Takagi K, Son HV. Simulation of mefenacit concentrations in paddy fields by an improved PCPF-1 model. Pest Manag. Sci. 2006; 62: 20–29. https://doi.org/10.1002/ps.1115.
69. Mohammad A, Sudhishri S, Das TK, Singh M, Bhattacharyya R, Dass A, Khanna M, Sharma VK, Dwivedi N, Kumar M. Water balance in direct-seeded rice under 549 conservation agriculture in North-western Indo-Gangetic Plains of India. Irrig. Sci. 2018; 35; 381–550 393. https://doi.org/10.1007/s00271-018-0590-z.
70. Bouman BAM, Lampayan RM, Tuong TP. Water management in irrigated rice: Coping with water scarcity. Int. Rice Res. Inst. Los Baños, Philippines. 2007; 54 p.
71. Maria CD, Bischetti S, Chiaradia GB, Facchi A, Minioti EF, Rienzner M, Romani M, Tenni D, Gandolfi C. The role of water management and environmental factors on field irrigation requirements and water productivity of rice. Irrig. Sci. 2017; 35: 11–26. https://doi.org/10.1007/s00271-016-0519-3
72. Darzi-Naftchali A, Karandish F, Šimůnek Numerical modeling of soil water dynamics in subsurface drained paddies with midseason drainage or alternate wetting and drying management. Agric. Water Manag. 2018; 197: 67–78. https://doi.org/10.1016/J.AGWAT.2017.11.017
73. Yin J, Zhang X, M.asce PE. Suction Measurement in freezing process using high-suction Tensiometer. Geo-Congress 2020 GSP 318 907. 907–12.
74. Cormier J, Depardieu C, Letourneau G, Boily C, Gallichand J, Caron J. Tensiometer-based irrigation scheduling and water use efficiency of field grown strawberries. Accepted in Agronomy journal. 2020 doi: 10.1002/agj2.20205.