



Tensiometers for Rice Water Footprints

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Author's contribution

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

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ABSTRACT

Water footprints (WFs) of rice are quite higher viz. 992 billion cubic metres per year ($\text{Gm}^3 \text{yr}^{-1}$) than from the other cereals which further responsible for the lower water productivity. Out of global WFs for crop production viz. $7404 \text{Gm}^3 \text{yr}^{-1}$ 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 Annually additional water of worth US \$ 39 million is withdrawn in NW Indian Punjab state for feeding crops, particularly rice.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.

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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 make 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 ($1087 \text{ Gm}^3 \text{ yr}^{-1}$), rice ($992 \text{ Gm}^3 \text{ yr}^{-1}$) and maize ($770 \text{ Gm}^3 \text{ yr}^{-1}$) [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 ($1047 \text{ Gm}^3 \text{ yr}^{-1}$), China ($967 \text{ Gm}^3 \text{ yr}^{-1}$) and the USA ($826 \text{ Gm}^3 \text{ yr}^{-1}$). A relatively large total blue water footprint as a result of crop production is observed in the Indus river basin ($117 \text{ Gm}^3 \text{ yr}^{-1}$) and the Ganges river basin ($108 \text{ Gm}^3 \text{ yr}^{-1}$). 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 $992 \text{ Gm}^3 \text{ yr}^{-1}$ [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.

“GRACE”- satellite delineated to within 440,000 km² area of North India, underground water levels falls at a rate of 30 cm year⁻¹ that further meant the loss of under-ground water to 18 km³ year⁻¹ [7]. A recent report estimates that global water withdrawal will grow from 4,500 billion m³ year⁻¹ today to 6,900 billion m³ year⁻¹ by 2030 [8] Already, N fertilizers consumption hiked to 9.13 times from 1960 to 2017 [9] for which ever increasing population pressure and reduced N recoveries from 80% in 1960 to 30% in 2000 in cereals are the critical factors [10]. Upto 2050, food production must be enhanced to 70% and that too have to met with shrinking resources of

land and water [11] Hence annual cereal production must be increased to 43 million metric tones [12,13] (Fig.1). Therefore, not only yields but land or water productivity should be enhanced for sustainable productivity by reducing the water footprints (WFs) of the rice-wheat cropping sequence in general and of rice in particular [12,14] as it occupies 22.9% of the global cultivable area [15]. Intensively cultivated rice-wheat cropping sequence has emerged with many sustainability issues [16,17,18,19,20] out of which declined underground water tables is an major issue, as conventional methods of crop establishments viz. puddling and irrigations viz. flood irrigation involved large water inputs [16,17,18]. In NW India, Underground water table is declining at a faster rate, hence farmers have to deepen their borewells for getting enough water to feed their crops.

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

1 acre=4000 sq. m
1 irrigation= 10 cm= 0.10m
25 irrigation= 250 cm=2.50m
Total water used=4000 x 2.50=10,000 m ³
1 m ³ = 1000 ltr
10,000 m ³ = 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



Fig. 1. Deepening of the bores of the tubewells because of declined underground water table

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. TENSIO METER 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

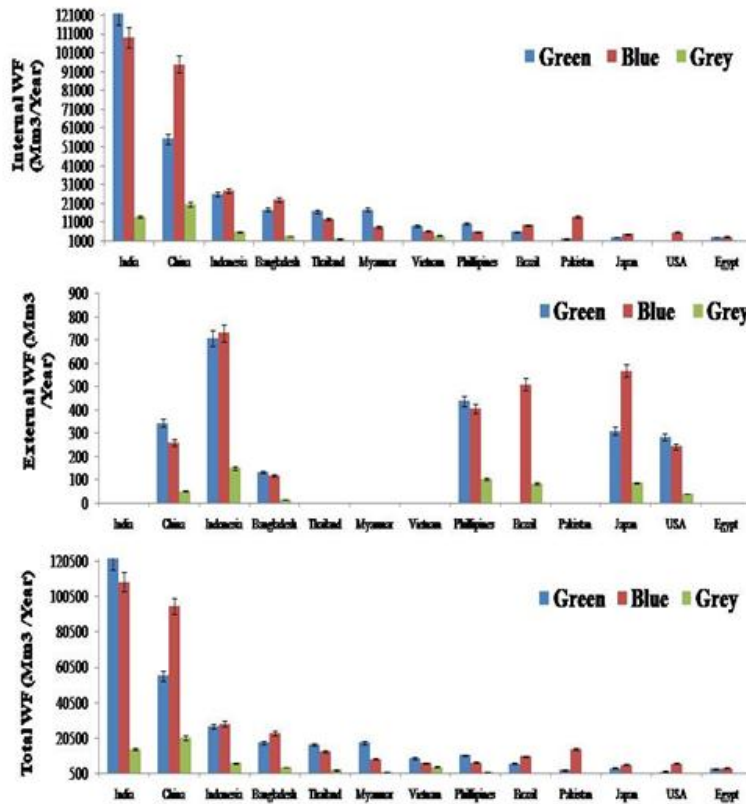


Fig. 2. Global rice water footprints including internal, external and total water footprints (Mm3 Year⁻¹) Source: [19,2]

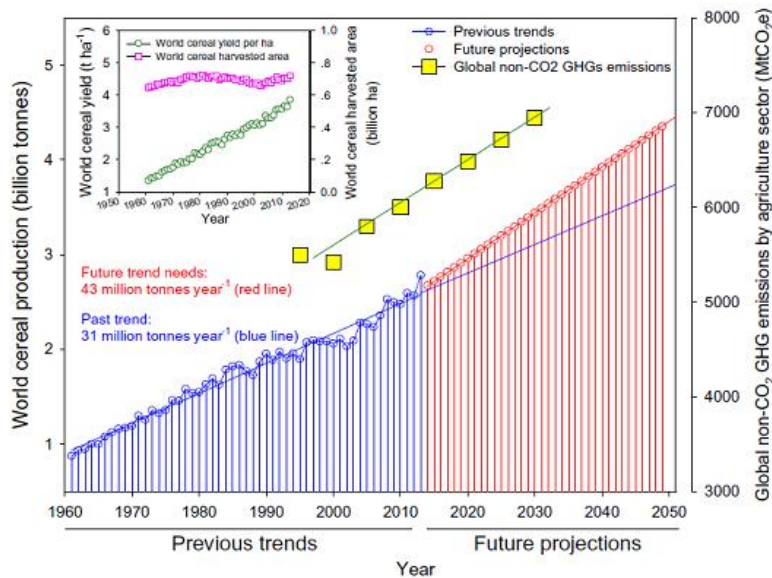


Fig. 3. World cereal production targets and global non-CO₂ greenhouse gas (GHG) emissions by agriculture sector [11]

<http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html>

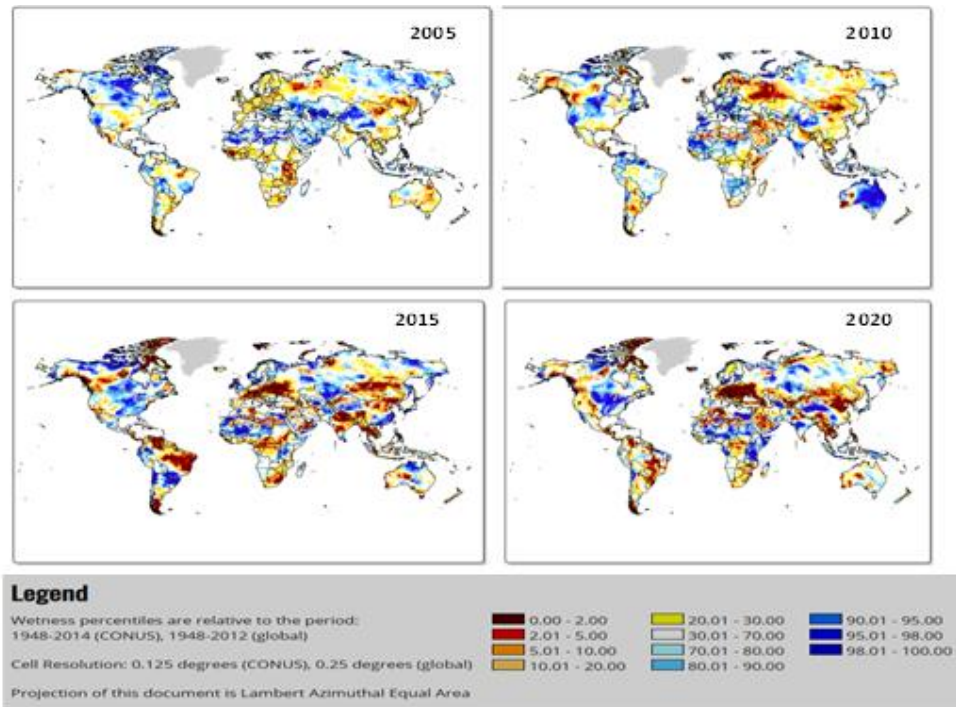


Fig. 4. Temporal changes in Global ground water trends from 2005 to 2020
(Compiled by Bhatt.R Source: <https://nasagrace.ul.edu/Slider.aspx>)

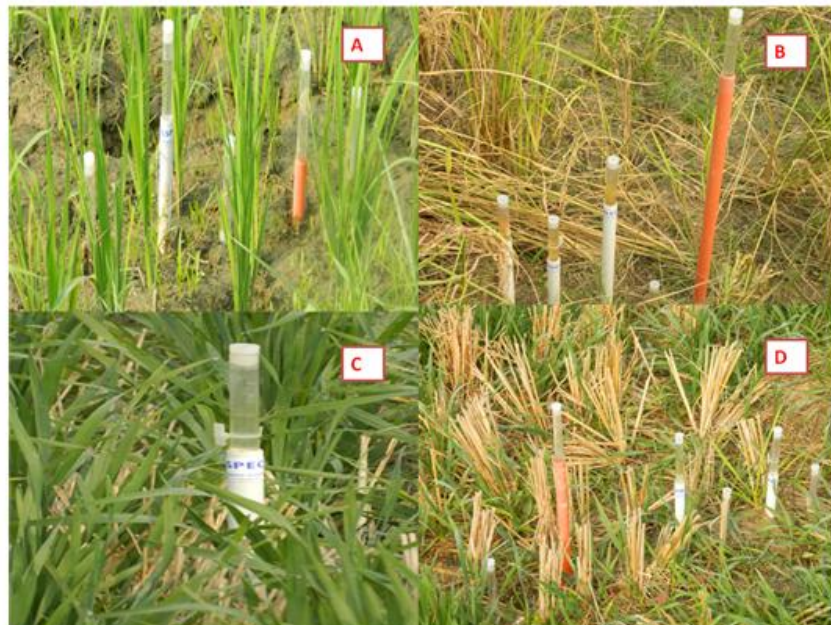


Fig. 5. View of installed tensiometers of differential lengths in rice (A,B) and wheat (C,D)
Source: [34]



Fig. 6. Tensiometer recommended for the rice farmers Source: [36]

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 detained 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

$$k = VI/(T\Delta H)$$

where V is the volume of water that flows through the cup in time T when a hydraulic head difference ΔH 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 TENSIO METERS

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 syring 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

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 resist 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 tensimeter 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

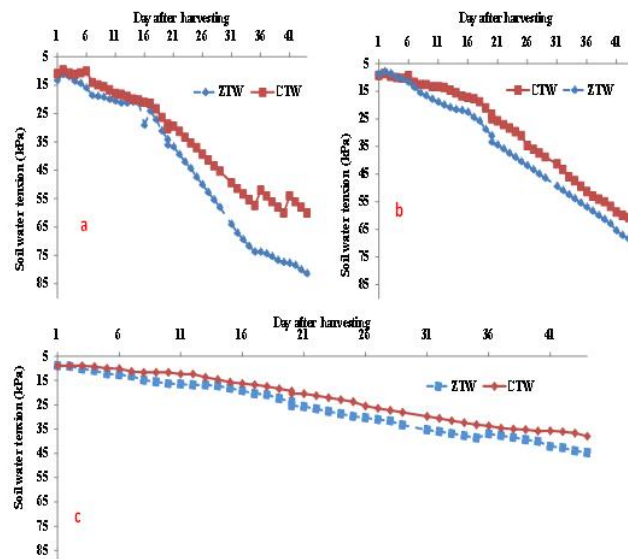


Fig. 7. Soil matric potential as affected by tillage treatments during the intervening period between wheat and rice at (a) 10 cm , (b) 20 cm and (c) 30 soil depths (Source [34])

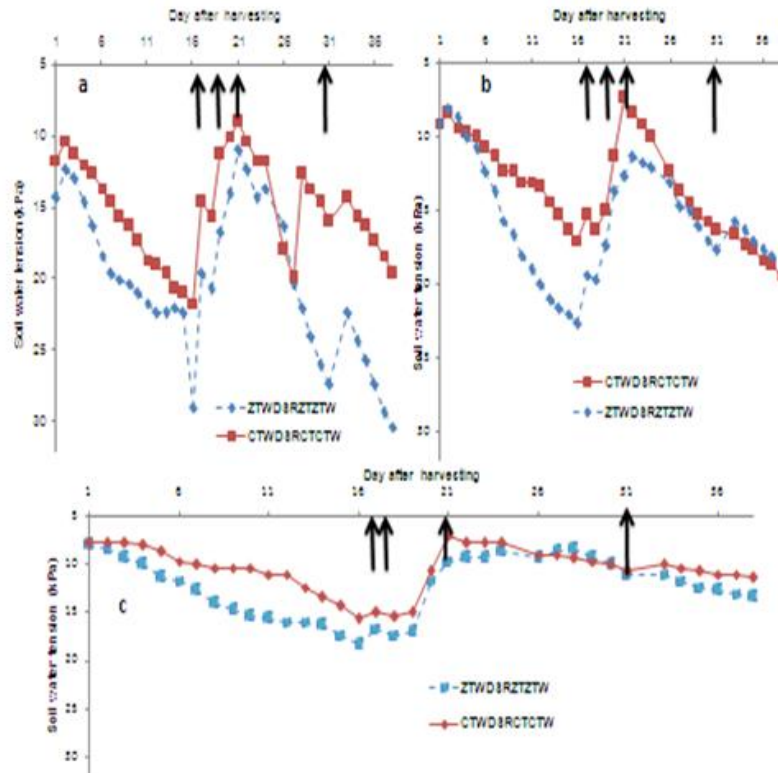


Fig. 8. Soil matric potential as affected by tillage treatments during the intervening period between wheat and rice at (a) 10 cm, (b) 20 cm and (c) 30 soil depths. (Arrows depicting rainfall events) Source [33,39]

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. TENSIO METER 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 scenarios was almost similar unlike as in 2012-13 (Fig. 10C). In rice, SMP profiles at different depths (Fig. 10B). during 2013 and during 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].

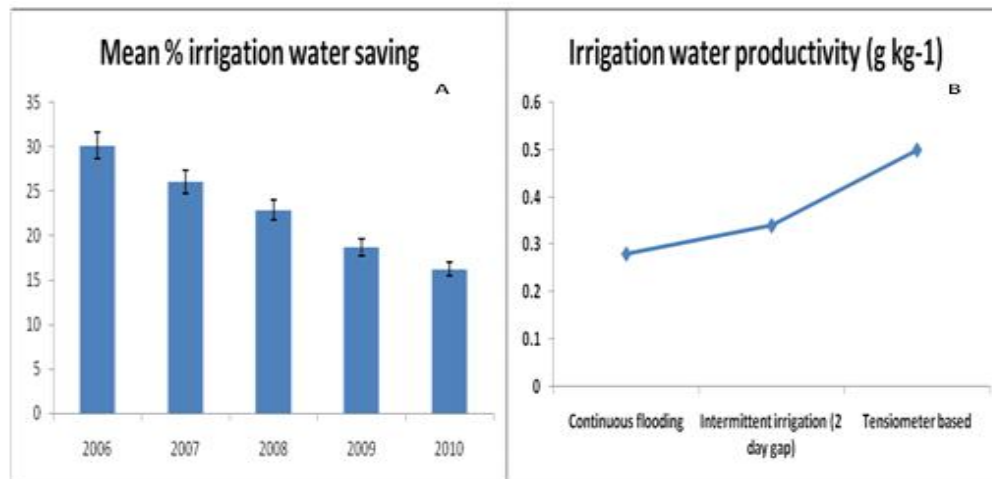


Fig. 9 Mean % Irrigation savings with tensiometers at Kapurthala district of Punjab [7] and water productivity under different irrigation options [1]

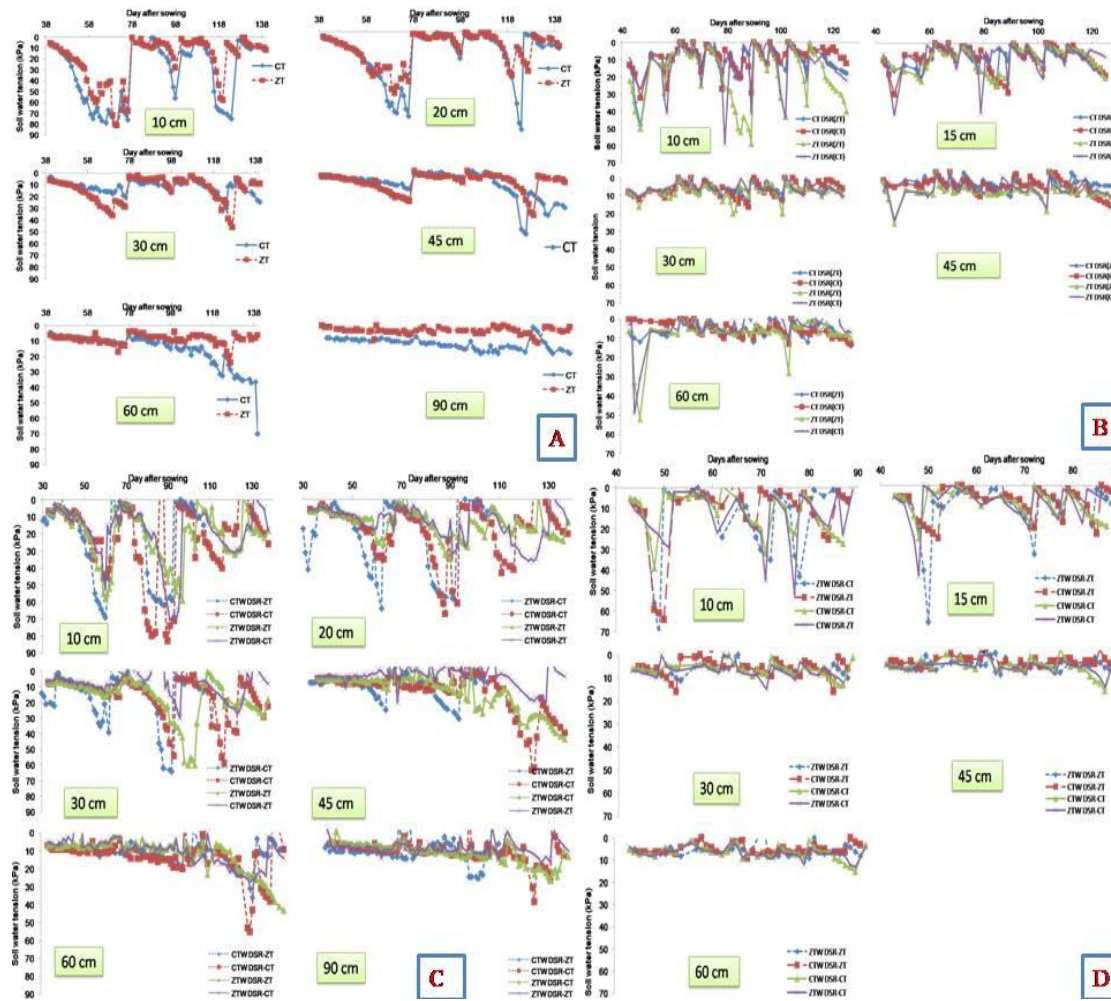


Fig. 10. Tensiometer readings in wheat at different soil depth in relation to CT and ZT plots in wheat during 2012-13 [A] and 2013-14 [C] and in rice at different soil depths during 2013 [B] and 2014 [D] under different establishment methods viz, direct seeded rice and mechanical transplanting under 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 Kukul

[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

$$q = \frac{K \cdot \Delta \Psi_t}{L}$$

Ψ_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.

$$q = K \cdot \Delta \Psi_t / L$$

$$q = \frac{K \cdot \Delta \Psi_A - \Delta \Psi_B}{L}$$

$$q = K \cdot \{(\text{Tensiometer readings at 45cm-45}) - (\text{Tensiometer readings at 60cm-60})\} / 15$$

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 footprint 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 make 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 than 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 adoption 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⁻¹

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 brining 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 touch 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.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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