Pak. J. Agri. Sci., Vol. 57(5), 1293-1301;2020
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:10.21162/PAKJAS/20.83
http://www.pakjas.com.pk

SENSOR BASED DRIP IRRIGATION TO ENHANCE CROP YIELD AND WATER PRODUCTIVITY IN SEMI-ARID CLIMATIC REGION OF PAKISTAN

Usman Zafar[1,*], Muhammad Arshad[1], Muhammad Jehanzeb Masud Cheema[1] and Riaz Ahmad[2]

[1] Department of Irrigation and Drainage, University of Agriculture, Faisalabad -Pakistan
[2]Deparment of Agronomy, University of Agriculture, Faisalabad -Pakistan.
***Corresponding author's e-mail: usmanengfsd@gmail.com**

The efficient application of irrigation and fertilizer are very important for optimizing crop water productivity and water losses even in drip irrigation. The application of sensor for monitoring of soil moisture and quantifying irrigation water is the valuable instrument for irrigation scheduling and water saving. Thus, a research study was conducted at Water Management Research Centre (PARAS), University of Agriculture Faisalabad, Pakistan to measure crop production response to water deficit and fertilizer levels in sensor-based drip irrigation system. The present study was also consisted IT-based web server for monitoring soil moisture status and subsequently served as decision support system for applying irrigation to the crops. Therefore, experiments were conducted on wheat crop with following treatments: five irrigation levels {sensor-based irrigation at CWR(SD_1), 15%(SD_2), 30(SD_3), 50(SD_4)% MAD compared with conventional time-based (TD) drip irrigation system} and three fertilizer levels {100%(F_1), 80%(F_2) and 60%(F_3) of recommended fertilizer}. The average results of wheat crop revealed that grain yield was 30.5, 18.27, 24.63 and 13.87% higher in SD_1, SD_2, SD_3, SD_4 compared to TD, respectively under F_1 fertilizer treatments in each. Among sensor-based drip irrigation (SD) treatments, water saving was more in SD4 but produced less crop yield than other treatments. Consequently, the higher water productivity was achieved in SD4 but resulted grain yield loss. Fertilizer treatments were also showed significant impact on crop yield and soil fertility. Comparatively, SD_2F_2 at 15% MAD level and 20% less fertilizer produced higher yield and water productivity conceived as novel concept that save water in addition to higher grain yield. Therefore, irrigating using sensors at 30% less then field capacity and 20% less then recommended dose would be recommended.

Keywords: Deficit irrigation, Sensor-based irrigation, Nutrient balance, Yield components, Drip fertigation.

INTRODUCTION

Optimized application of irrigation water and fertilizer are very important for irrigation system design, water saving, energy, cost saving and avoiding environmental hazards (Irfan *et al.*, 2014; Annandale *et al.*, 1999). Water saving along with considerable high yield can be obtained by successful adoption of drip technology (Uddin and Dhar, 2020; Barkunan *et al.*, 2019). Any system either drip, sprinkler or surface can be automatically operated with help of devices control timers, sensors or computers or mechanical appliances (Fidelis and Idim, 2020; Barkunan *et al.*, 2019). This help in efficient and economical application of water, conversely farmers can work on additional alternative necessary agricultural tasks. While, such systems are relatively costly and extremely complicated in its design and could prerequisites professionals to plan and implement it. An automatic programmed irrigation system reflects the use of the structural system needs no requirement or minor of physical involvement beside the inspection (Deekshithulu *et al.*, 2018). Fertilizer is also essential for crop growth, efficient management of fertilizer along with irrigation system is also plays important role to enhance crop production. In many part of the world, infertile soil leads towards for yield reduction (Cornish *et al.*, 2020; Jiang *et al.*, 2016; Palta *et al.*, 2005).

The most significant benefit of irrigation includes the reduction of impact of water stress, increased investment in standard requirement of inputs such as fertilizer and reliably improved variety affected by ambiguity of production of crops under rain fed conditions (Hillel and Vlek, 2005). Irrigation too provides a possibility for multiple cropping per year, especially in areas with prolonged dry periods (Fatima *et al.*, 2020; Hillel and Vlek, 2005). Massive output return of agricultural production can be achieved through maintaining environmental quality and efficiently management of inputs practicing like irrigation scheduling and efficient use of fertilizers (Macintosh *et al.*, 2019; Willy *et al.*, 2019). Appropriate irrigation regimes are best practice that facilitates an irrigator to use proper amount of water at the right time for crop production (Pratt *et al.*, 2019; Zhang *et al.*, 2019). The water losses in drip or surface irrigation systems result in ample nutrient loss through deep per percolation (Hussain *et al.*, 2020; Singandhupe *et al.*, 2003).

The various irrigational pattern approaches can apply on soil, plant and atmosphere ecologically or an interaction of two or three factors to check soil-plant-atmosphere continuum

(SPAC) to check their basic compatibility (Novák *et al.*, 2019). Under deficit irrigation, cost of crop production can be reduced as well as shortage of water is also help in water conservation and lowest the leaching down of nutrients and pesticides pollutants into under groundwater. On the other hand, before executing such a tactic across all crops, there is prerequisite to investigate the advantages and disadvantages of deficit irrigation, particularly for water stress sensitive crops (Tura and Tolossa, 2020; Rafi *et al.*, 2019).

The sensor based drip irrigation system is the best solution to prevailing water scarcity in many countries. In Pakistan, water resources are rapidly shrinking day by day and usage of efficient way of irrigation is very significant and it's has been acknowledged that irrigation by drip is incredibly reasonable economical and effective. In typical drip irrigation system, the farmer should keep watch on irrigation timetable that is totally different for various crops. This is a cumbersome and hectic activity for an ordinary farmer. Therefore, need of the hour that an automatic micro-controller based drip irrigation system, irrigation must be developed which applies water only when there is intense requirement of water. Presently, there is dire need to automate and facilitate the drip irrigation system using sensors network. Drip irrigation system not limited to save irrigation water, it can be useful for efficient application of fertilizer (Chandramohan *et al.*, 2019). Yan *et al.* (2019) observed irrigation and fertilization impact on winter wheat at Yangling, China and found that the maximum grain weight percentage of spike weight was about 80% under the moderate water and fertilizer supply conditions.

Therefore, keeping in view the importance of optimum irrigation and fertigation scheduling, for the successful operation and management of drip irrigation for various crops, the present study was planned. This study investigated the application of a sensor network for low-cost drip irrigation solution with following key objectives: 1) To develop and utilize sensor network for soil moisture monitoring in semi-arid climatic region; 2) To develop irrigation schedules using soil moisture sensors under different soil moisture depletion and fertilizer levels for wheat crop and 3) To evaluate wheat crop yield and water productivity of sensor-based against conventional drip irrigation system on bed-furrow system.

MATERIALS AND METHODS

***Site description*:** The field experiments were conducted in the Water Management Research Centre (PARAS), University of

Table 1. Representative physical properties of soil.

Soil Texture	Saturated Hydraulic Conductivity K_s	Total Pore Spaces (e)	Apparent Specific Gravity (A_s)	Field Capacity (F_c)	Permanent Wilting Point (PWP)	Total Available water (AW)	
	(mm/h)	(% by Vol.)	(A_s)	(% by Vol.)	(% by Vol.)	(% by Vol)	AW=0.1×V (mm/cm)
Loam	12 (8-20)	47 (43-49)	1.40 (1.34-1.5)	31 (25-36)	14 (11-17)	17 (14-20)	1.7 (1.4-2.0)

Note: Normal ranges are shown in parenthesis, Source: Hansen et al. (1980)

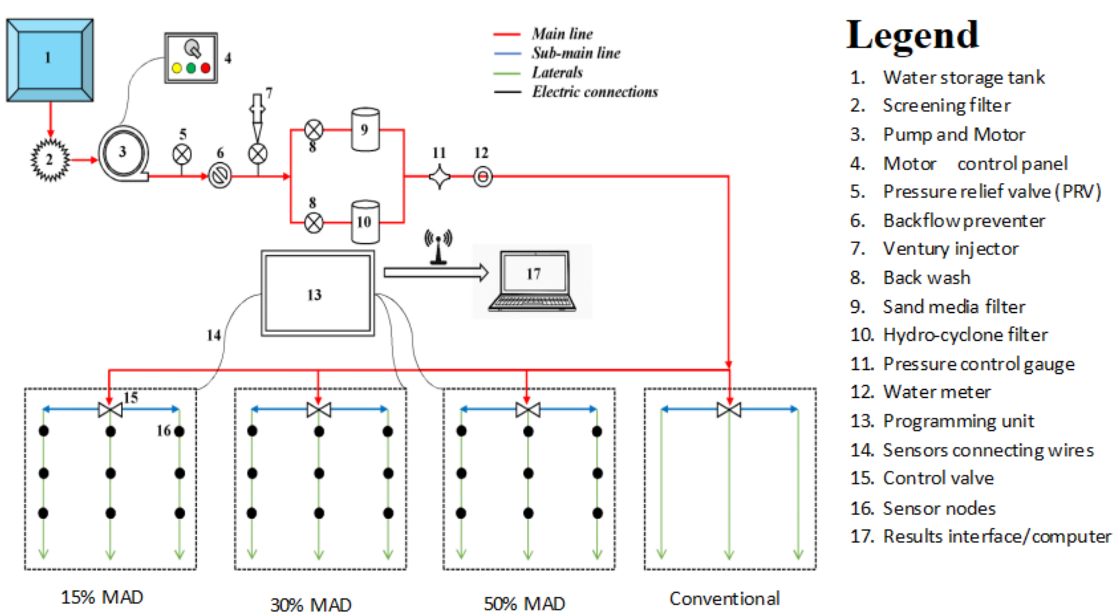

Figure 1. Design layout of drip irrigation system.

Agriculture Faisalabad, Pakistan located at Lat 31.386° and Lon 72.999°. Data for wheat crop under sensor-based irrigation for different MAD and fertilizer levels were collected for two years (2016-17 and 2017-18). The climatic data for the growing period of crop were collected from the meteorological observatory present at the site. The study area has hot and arid climate with very seasonal rainfall prevails in most part of the system. The quality of groundwater is marginal to good. The cropping pattern of the area includes high return crops. During Rabi and Kharif season farmer use to grow Cotton, Rice, Sugarcane, seasonal Oilseeds, Fodders, Wheat, Maize and Vegetables. In addition to this the orchards (mainly citrus, Mango, Guava) also exist on the significant portion of the irrigated area.

Soil samples of 1-30 cm were taken from the randomly selected field. The textural class of soil was found loam and average bulk density was found to be 1.21 g/cc (Gram per cubic centimetre). The other important physical properties are given in Table 1.

Design layout of drip irrigation system: The layout of raised bed planting system each zone comprises of Bed-Furrow system having dimension of 61cm × 30.5cm and there were six beds in each treatment. The laterals were installed in the center of the bed. The design layout of drip irrigation system is presented in Figure 1.

Design of experiments: The evaluation of sensor-based drip irrigation system (SD) against conventional time-based drip irrigation system (TD), three irrigation scheduling levels based on Management Allowed Deficit (MAD) i.e. 15%, 30% and 50% were applied to conserve maximum amount of water. In order to optimize crop water productivity in drip irrigation system, three fertilizer levels i.e. 100, 80 and 60% of recommended fertilizer were applied with each MAD level. Experiments were conducted under RCBD (Randomized Complete Block Design) with three replications of each treatment. The treatments were named as i.e. SD_1: Irrigation at CWR, SD_2: Irrigation at 15% MAD, SD_3: Irrigation at 30% MAD, SD_4: Irrigation at 50% MAD, TD: Conventional time-based drip irrigation, F_1: 100% of recommended fertilizer, F_2: 80% of recommended fertilizer and F_3: 60% of recommended fertilizer.

Field operation**:** Wheat (cv. Inqilab-91) was sown in the field on 15 Nov. 2016 and 16 Nov. 2017, respectively. SD_1 was applied according to crop water requirement (CWR) which is equal to field capacity. SD_2 applied at 15, 30 and 50% MAD level below field capacity, respectively. All the treatments were refilled to their desired level when they fall below 15, 30 and 50% of their level according to calibrated reading of sensor with moisture content acquired by gravimetric method at the same point. In SD_5 conventional practice was followed by operating at a fix peak time operation of drip system for applying irrigation for entire season. The operation time for all season was calculated with one peak season Kc value which was 1.2 for the region. The recommended fertilizers containing DAP, Urea and Potash were applied at the rate of 100, 75 and 50kg/ha, respectively.

Development of soil moisture sensor and networking protocol:

Soil moisture sensor**:** Following is the stepwise procedure for the development of soil moisture sensor and networking protocol. In this experimental research study, spark fun soil moisture sensor (SEN-13322) were used. These sensors read resistance in soil, more water in soil gives less resistance and vice versa. External hardware like microcontroller were used to read this resistance variation. Furthermore, resistance can be calibrated with moisture content for useful agricultural application (Kumar *et al.,* 2018; Corwin and Lesch, 2003). This sensor gives voltage 0-5 volts depending upon amount of water in soil. Microcontroller has capability to disperse these 5 volts in 10-bit resolution e.g. 1024 parts. Sensor gave its final value between 0-1024.

Arduino microcontroller was used in each node to collect information of each sensor and transmit it to the main server. Arduino UNO used atmega-328 chip to perform functions. It reads digital and analogue input and outputs and it was powered up with 5V USB cable with any battery. Boards were powered up by lithium ion rechargeable battery of 3.7 volts. Microcontroller can run on these batteries upto four days. However, solar panels were used to automatically recharge the batteries during its proper function. 5v 500mA solar panels were used for this purpose.

Networking protocol**:** The node Sensor Architecture of the micro controller is presented in Figure 2. Message Queuing Telemetry Transport (MQTT) protocol was used for sensor, server and web communication. MQTT is light weight subscribing and publishing service. This protocol originally developed by IBM. Because of its light weight, simplicity and wide applications it is using successfully for wireless sensors network (Bandaranayake *et al.,* 2018; Kumar *et al.,* 2018; Alam *et al.,* 2018). To work with wireless sensor network, this protocol needs a broker, which collect information from the sensors and publish it online or website. Mosquito broker was used for this application in this system.

Main server consisted on the following hardware and software: Computer, GSM module, Relays, System power, Networking protocol and Communication Module. Credit card size, Linux operated Raspberry Pi3 model B was used in this system, which acted as server for the whole system. A microprocessor 1.2 GHz 64-bit quad core embedded is this mini-computer which is powerful enough to handle communication between sensors. It has an integrated Wi-Fi chip, which serves the purpose the communication between sensors.

Global system for mobile (GSM) was used to send text messages to user by the server when any activity occurs in the system e.g. moisture threshold value reaches. GSM working is same as the ordinary cell phone, but it can be controlled by microcontrollers unlike cell phone. In this experiment, GSM used to send irrigation alert about the current situation of water. Moreover, relays were controlled directly with the GSM or by the server i.e. by dialing GSM sim card number, pump can be turned ON/OFF.

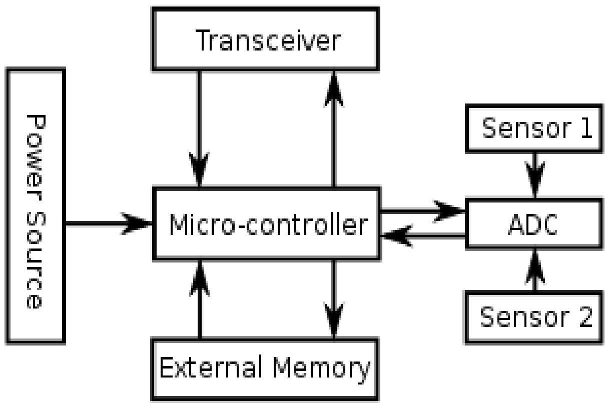

Figure 2. Node sensor architecture.

Measurement of water balance: The calculation of field water balance components is very important for effective irrigation managements and decrease in water losses (Valayamkunnath *et al.*, 2019). The water balance of the root zone of a cropped field was calculated using the Equation 1 (Andrew et al.,1997):

$$I + R = ET_c + P + S + R_{off} + d_w \quad \text{(Eq.1)}$$

Where, I is irrigation applied (mm), R is rainfall measured (mm), ET_c is crop evapotranspiration (mm/day), P is percolation below root zone (mm), S is seepage (mm), $R_{off}$is runoff (mm), d_w is the change in the soil water storage in root zone (mm). Irrigation water applied in each treatment was measured by as residual of water balance equation. Rainfall was measured by rain gauges installed at the experimental site. Evaporation pan was installed on the site to measure the evaporation and equations 2 & 3 were used for the calculation of evapotranspiration.

$$ET_o = K_{pan} x E_{pan} \quad \text{(Eq.2)}$$

$$ET_c = K_c x ET_o \quad \text{(Eq.3)}$$

Where, ET_o is the reference evapotranspiration (mm/day), K_{pan} is pan coefficient, E_{pan} evaporation from pan, ET_c crop evapotranspiration (mm/day) and K_c is crop factor. Percolation was measured by using percolator 45 cm in length driving 30 cm into the soil and 15 cm above the soil surface with a lid upon it to prevent evaporation losses from the cylinder.

RESULTS

***Calibration of Sensor*:** Spark fun moisture sensors SEN-13322 were used in this research. They proved useful in calculating moisture content. Before developing the sensor network, the sensors accuracy was assessed with the already developed "Sensor based Precision Irrigation" prototype. A successful relationship was attained between moisture content and resistivity. A high coefficient of determination was found as 0.98 (Figure 3), showing that these sensors are suitable to use for irrigation scheduling.

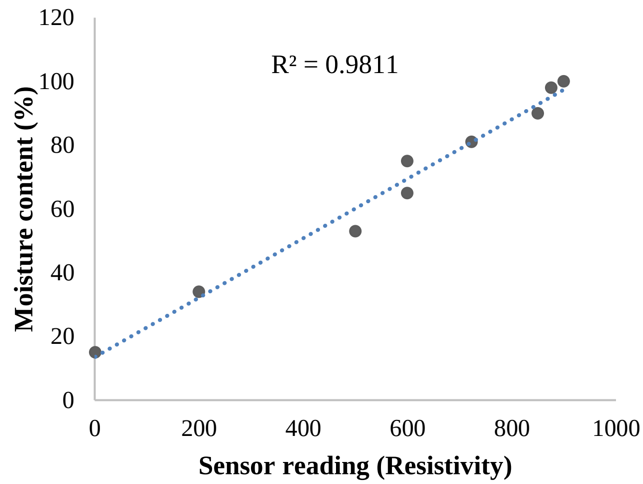

Figure 3. Correlation between sensors reading and moisture content

Water Balance: The results of water balance for wheat on drip irrigation system for both years are shown in Table 2. There was huge difference in water balance parameters during two seasons and among the different treatments as well. Keeping in view the seasonal differences irrigation applied (I) was lowest in SDI_4 in both the years followed by SD_3, SD_2 and SD_1. The irrigation amount varied from 230.46 to 460.93 mm and 258.41 mm to 516.83 mm for Wheat due to different MAD based irrigation treatments in two years respectively. Maximum amount of applied water 1035.1 and 1091mm was observed in TD of conventional irrigation. More irrigation was applied in season 2 due to less rainfall as compared to year 1 computed to be 61 mm and 116.9mm respectively. The irrigation applied was up to field capacity and below field capacity under three MAD levels, hence percolation was only observed in case of heavy rains and it was assumed to be 10% of the available water through precipitation after Talebpour *et al.* (2017). The total change in stored water, d_w, was calculated as residual of water balance equation. Runoff and Seepage were assumed to be zero because each treatment was separated by bund from others. The similar water balance equation was used by Dar et al. (2017) and Choudhury et al. (2006) and found satisfactory results.

***Wheat Growth Components*:** Growth characters of wheat crop such as number of plants, plant height, spike length, 1000-grain weight, biological yield, harvest index, grain yield and crop water productivity grown during the years 2016. These parameters are important to determine crop physical health and yield. Results revealed that the sensor based drip irrigation system, management allowed deficit levels and

Table 2. Water balance of wheat crop for both cropping years

Treatments	I (mm)	R (mm)	ET_c (mm)	P (mm)	dW (mm)	R_{off} (mm)	S (mm)
			Year 2016-17				
SD1 (FC)	460.93	116.9	522.3	11.7	43.8	0	0.0
SD2 (15% MAD)	391.79	116.9	522.3	11.7	-25.3	0	0.0
SD3 (30% MAD)	322.65	116.9	522.3	11.7	-94.4	0	0.0
SD4 (50% MAD)	230.46	116.9	522.3	11.7	-186.6	0	0.0
TD (Conventional)	1035.1	116.9	522.3	11.7	618.0	0	0.0
			Year 2017-18				
SD1 (FC)	516.83	61	567.8	6.1	3.9	0	0.0
SD2 (15% MAD)	439.3	61	567.8	6.1	-73.6	0	0.0
SD3 (30% MAD)	361.81	61	567.8	6.1	-151.1	0	0.0
SD4 (50% MAD)	258.41	61	567.8	6.1	-254.5	0	0.0
TD (Conventional)	1091	61	567.8	6.1	578.1	0	0.0

I =irrigation applied, R =rainfall, ETc =crop evapotranspiration, P =percolation, S = seepage, R_{off} = runoff ,dw = change in water storage

different fertilizer doses had a clear impact on the agronomical characteristics of wheat crop. The results revealed that the number of plants per unit area were found maximum (233m^{-2}) in SD_1F_1 for both growing years. The highest average plant of 96.1cm was recorded in SD_1F_1 and lowest of 92.5mm in both SD_5F_2 and SD_5F_3. The highest average spike length of 10.4cm was found in SD_1 followed by SD_2 (10.3cm) and SD_3 (9.8cm). The average maximum grain yields (GY) 4450 kg/ha of wheat crop were recorded in both SD1F1 and SD1F2 and SD5F3 yielded 3110 kg/ha lowest average among all treatments (Fig. 4).

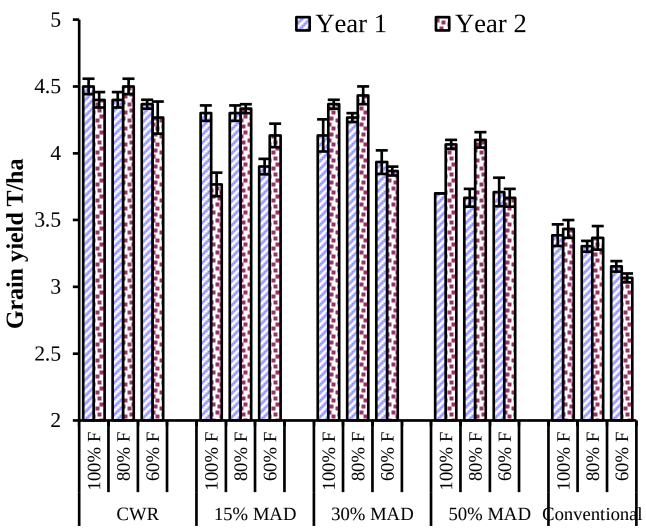

Figure 4. Yearly means of grain yield (T/ha)

The average maximum 1000-grain weight of wheat crop was found 36 in SD_1F_2 while the lowest in SD5F3 (29.2). The harvest index of 32.9 was found maximum in SD3F1 compared with other treatments. Both SD1F1 and SD1F2 represented average highest biological yields of 13.7 tons per hector in both years, while lowest average was found in SD5F3 (27.0). Grain yield is the most crucial parameter and ultimate mission of farmers. Figure 5 shows the grain yield in tons per hectare of wheat crop under drip irrigation system for different scheduling and fertilizer levels. In season 2016-17, the highest wheat crop yield of 4.5T/ha was recorded in SD1F1, while the lowest yield of 3.2T/ha was recorded in SD5F3. In season 2017-18, the highest wheat crop yield was recorded in SD1F2 (4.5T/ha), while the lowest yield of 3.1T/ha was recorded in SD5F3. The seasonal average yield of crop yield was same in SD1F1 and SD1F2. The sensor based irrigation drip irrigation scheduled under crop water requirements and fertilizer levels yielded the highest wheat production in each year comparative to other all treatments.

***Depth of water applied*:** The depth of water applied including rainfall water was maintained according to sensor reading (Fig.5). The minimum amount of water was applied for SD_4 i.e. 50% of MAD treatment consuming 347.6 mm followed by 439.55, 508.69 and 577.83 mm in SD_3, SD_2 and SD_1 and maximum of 1113 mm in SD_5 of control treatment in year 1, respectively.

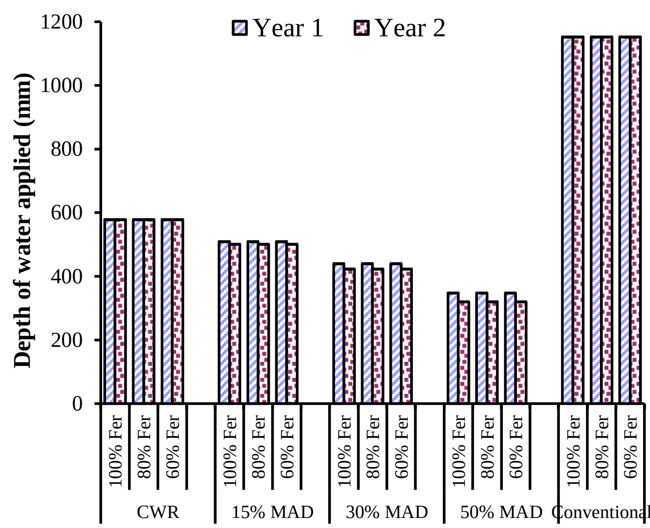

Figure 5. Yearly means of depth of water applied (mm)

***Statistical analysis*:** Results clearly revealed that high influence of sensor-based drip irrigation (SD) treatment on wheat yields and agronomical factors in both years over time-based irrigation (TD) treatment. The data obtained pointed out that a high significant effect of SD treatment on the average plant height (cm), spike length (cm), 1000 grain weight (g), total biological yield (ton h^{-1}) and total grain yield (ton h^{-1}), whereas, there was no significant effect on harvest index (HI).

***Water Productivity*:** Crop water productivity represents how efficiently water was used by crop. The difference in amount of irrigation water applied in both the years was subjected to amount of precipitation and soil moisture status by sensor. The results of wheat crop productivity after excluding rainfall from total water applied for both seasons were shown in Figure 6. The maximum water productivity 10.63 kg/ha/mm (kilogram per hectare per millimeter) was obtained in 50% MAD treatment (SD_4) followed by 9.35 kg/ha/mm in 30% MAD treatment (SD_3), 8.19 kg/ha/mm in 15% MAD treatment (SD_2) and 7.65 kg/ha/mm in CWR (SD_1) in season 1. In season 2, maximum water productivity of 12.35 kg/ha/mm was resulted in 50% MAD treatment (SD_4) followed by 9.99 kg/ha/mm in 30% MAD treatment (SD_3), 8.15 kg/ha/mm in 15% MAD treatment (SD_2) and 7.60 kg/ha/mm in CWR (SD_1). Lowest water productivity of 2.85 kg/ha/mm was found in conventional treatment SD_5.

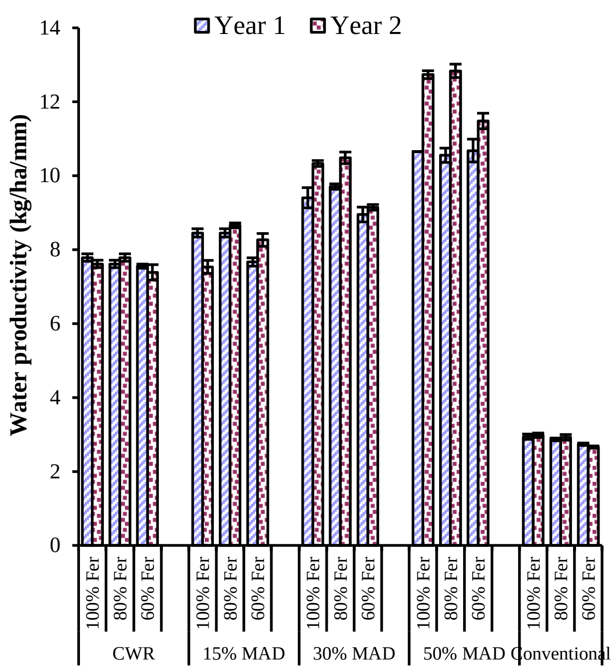

Figure 6. Yearly means of water productivity

***Nutrient Balance for Wheat*:** The nutrient balance results of wheat crop for both growing seasons were summarized in Figures 7, 8, 9 and10. The graphs presented that there was very minute change in organic matter (OM) of the soil in both years and all irrigation treatments have no significant change in soil residual in both years for all irrigation and fertilizer levels. Results reveal that soil is weak in OM and need farm yard manure (FYM) application for it rehabilitation. The N fertility also showed similar results and not a sharp change in soil fertility is observed in terms of N value as all treatments and levels differ non-significantly for the both years means soil is rich in N. However, in terms of P values, SD2 and SD4 of 15% MAD and 50% MAD at 100% and 60% amount of recommended dose of fertilizer differ significantly than other treatments in the year 1, while remained stagnant in year 2 with no significant difference. For P balance in the soil profile significant trend of optimization of fertilizer is observed in SD_2 of 80% fertilizer application which differs in both years. F_1 and F_3 also differ significantly in year 1 but remained non-significant in year 2. The effect of nitrogen (N) on the grain weight of cereals is complex. N plays a key role in crop productivity and significantly affects the grain weight of cereals (Khan *et al.*, 2020; Jiang *et al.*, 2016; Palta *et al.*, 2005). Phosphorus (P) fertilizer can improve the root growth and grain filling efficiency during drought to improve osmotic adjustment in crops (Jeong *et al.,* 2017)

The range of P value lies in medium fertile range so application of P will bring positive results in future. Comparison of means for K showed significant effect of F_3 and SD_3 in both years (Fig. 10). The residual value of K lies in range indicating that soil is weak and good crop production is not possible without application of Carmoa *et el.* (2017) also used similar equation for calculating nutrient balance in the soil. These results are also supported by Hokam *et al.* (2011), used similar approach of optimizing different fertilizer levels to optimize use of NPK for optimum crop yield.

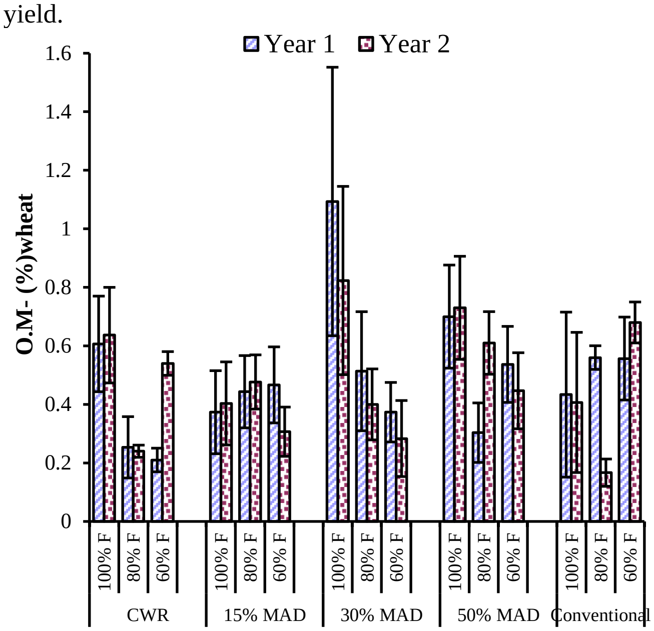

Figure 7. Comparison of variation in OM% for Wheat in Year 1 and Year 2

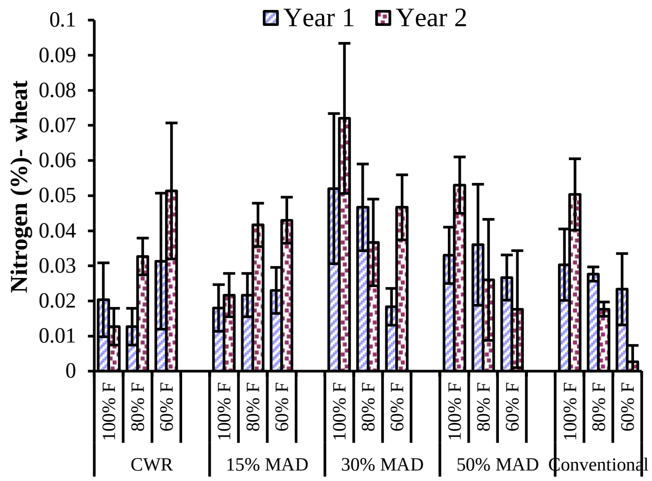

Figure 8. Comparison of variation in N for Wheat in Year 1 and Year 2

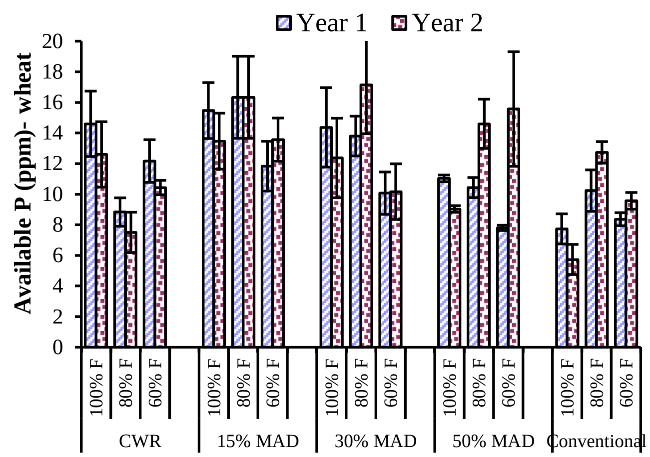

Figure 9. Comparison of means of P for wheat in Year 1 and Year 2

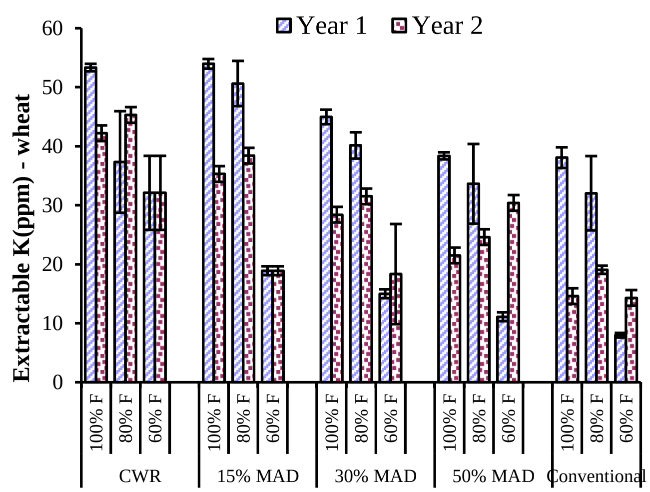

Figure 10. Comparison of means of K for wheat in Year 1 and Year 2

DISCUSSION

The irrigation water saving is high in case of sensor-based (SD) as compared to time-based (TD) conventional drip irrigation system as SD supplied more accurate and less amount of water according to the crop need. Moreover, the results revealed that ETc values in TD were higher that of SD during the entire season. This was due to the more accurate irrigation scheduling with SD as compared to TD, which leads to the availability of enough water in the root zone (Mason et al., 2019 and Prasojo *et al.,* 2020). The differences could be also resulted from the exact measurement of water requirements of the crop through application of calibrated soil moisture sensors. Furthermore, the MAD levels leads towards more water saving in SD. Results of the second season were found to be consistent with findings of the first season within each treatment, but a significant difference found among treatments. The consistency was a result of non-significant differences in measuring soil moisture in the sites of experiments.

The total applied irrigation water for SD_1 and TD was 557 and 1152 mm, respectively. This indicated that there was a 51% saving in irrigation water in case of SD compared to TD. The results indicated that much irrigation water was utilized under TD treatment. Hence, change in irrigation frequency and application stage could significantly affect the available soil water during wheat growing seasons (Bell *et al.,* 2020). However, these amounts are greater than the amount of irrigation water practiced by the framers in the area (Domínguez *et al*., 2020).

This study revealed that both main irrigation scheduling techniques under analysis had a clear impact on the agronomical characteristics of plant. The reason that the SD resulting in greater yield than TD could be attributed to variation in amount of water added to the two treatments. The 50% decreasing in moisture level (MAD 50% resulted in the significant yield reduction. While, the increased in moisture level in the root zone was reasonable for increasing the agronomical factors especially at field capacity in SD treatment. The decrease of soil aeration with low irrigation water added for SD4 treatment may be responsible for affecting all agronomical parameters (Girsang *et al.,* 2020). Therefore, conserving water is very important in semi-arid areas experiencing severe shortage such as Pakistan.

In general, the higher values of crop water productivity under SD are attributed to the saving of applied irrigation water. Therefore, the lower amount of water received was resulting in obtaining higher CWP (SD5). Generally, CWP can be increased by reducing irrigation water losses, fertilizer application, soil type, cultural and management practices (Ali and Talukder, 2008). The variation in CWP was almost consistent in the two growing seasons, which may be due to the less variation in weather conditions for both growing years. Under conditions of the two irrigation treatments in the both growing seasons, SD resulted in the highest CWP, followed by TD. It was apparent that the CWP of wheat decreased with more of water applied irrigation. The fertilizer application has also significant impact on crop water productivity and soil fertility.

Conclusions: The irrigation scheduling using soil-moisture sensor and fertigation levels for wheat crop under drip irrigation were compared for two year's field experiments in semi-arid region of Pakistan. It was concluded from the results that sensor-based drip irrigation (SD) proved considerable benefits, its precise covering irrigation requirements, higher yield and water saving over conventional time-based drip irrigation (TD) system. The results commented that TD induced plenty of water losses (595mm per season) resulted less water productivity. Among deficit irrigation scheduling and 100% recommended fertilizer dose, the least amount of water 319 mm was applied in SD4 but resulted crop stress. Thus, maximum crop water productivity (CWP) was observed under SD4 but relative less crop yield. The maximum grain yield of 4450kg/ha was observed in SD1 without grain losses, turned out in 9.37, 4.49, 12.74 and 23.37% higher crop yield then SD2, SD3, SD4 and TD. Fertilizer treatments also has significant effect on the crop yield and water productivity. Therefore, irrigating using sensors at 30% less then field capacity and 20% less then recommended dose would be recommended due to its optimum water saving, crop yield fertilizer saving and water productivity. Therefore, conserving water and fertilizer was no-doubt very crucial to produce crop economically for the farmers of semi-arid region like Pakistan.

REFERENCES

Ali, M.H. and M.S.U. Talukder. 2008. Increasing water productivity in crop production-a synthesis. Agric. Water Manage. 95:1201-1213.

Alam, I., R.A. James, V. Padmanbhan and A. Sunny. 2018. A low-cost automated irrigation system with soil moisture sensor. Int. Res. J. 5:4146-4148.

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

Annandale, J.G., N. Benade, N.Z. Jovanovic, J.M. Steyn and N. du Sautoy. 1999. Facilitating irrigation scheduling by means of the soil water balance model. Water Research Commission (WRC) Report No 753/1/99, Pretoria, South Africa.

Bandaranayake, W.M., D.M. Kadyampakeni and L.R. Parsons. 2018. Temporal changes of soil water in sandy soils amended with pine bark and efficient blueberry irrigation. Soil Sci. Soc. Am. J. 82:413-422.

Barkunan, S.R., V. Bhanumathi and J. Sethuram. 2019. Smart sensor for automatic drip irrigation system for paddy cultivation. Comput. Electr. Eng.73:180-193.

Bell, J.M., R.C. Schwartz,K.J. McInnes, T.A. Howell and C.L. Morgan. 2020. Effects of irrigation level and timing on profile soil water use by grain sorghum. Agric. Water Manage. 232:106030.

Chandramohan, P., P. Balamurugan and S. Dinesh. 2019. Effect of fluid flow diversion and venturi size on drip irrigation fertilizer feeding system. Flow Meas. Instrum. 65:250-256.

Cornish, P.S., A. Kumar and S. Das. 2020. Soil fertility along toposequences of the east India plateau and implications for productivity and sustainability. Soil Discussions.Pp.1-19.

Corwin, D.L. and S.M. Lesch. 2003. Application of soil electrical conductivity to precision agriculture: theory, principles, and guidelines. Agron. J. 95:455-471.

Dar, E.A., A.S. Brar and K.B. Singh. 2017. Water use and productivity of drip irrigated wheat under variable climatic and soil moisture regimes in North-West. India. Agric. Ecosyst. Environ. 248:9-19.

Deekshithulu, N.G., G.R. Babu, R.G. Babu and M.S. Ramakrishna. 2018. Development of software for the microcontroller based automated drip irrigation system using soil moisture sensor. Int. J. Curr. Microbiol. App. Sci. 7:1385-1393.

Domínguez-Niño, J.M., J. Oliver-Manera, J. Girona and J. Casadesús. 2020. Differential irrigation scheduling by an automated algorithm of water balance tuned by capacitance-type soil moisture sensors. Agric. Water Manage. 228:105880-105892.

Fatima, H., L.K. Almas and S. Haroon. 2020. Comparative water efficiency analysis of sole and multiple cropping systems under tunnel farming in Punjab-Pakistan. J. Water Res. Prot. 12:455.

Fidelis, I.S. and I.A. Idim. 2020. Design and Implementation of Solar Powered Automatic Irrigation System. Am. J. Electri. and Com. Eng. 4:1-9.

Girsang, S.S., T.Q.Correa Jr, J.R. Quilty, P.B. Sanchez and R.J. Buresh. 2020. Soil aeration and relationship to inorganic nitrogen during aerobic cultivation of irrigated rice on a consolidated land parcel. Soil Till. 202: 104647-104662.

Guanochanga, B., R. Cachipuendo, W. Fuertes, S. Salvador, D. S. Benítez, T. Toulkeridis, J. Torres, C. Villacís, F. Tapia and F. Meneses. 2018. November. Real-time air pollution monitoring systems using wireless sensor networks connected in a cloud-computing, wrapped up web services. In Proceedings of the Future Technologies Conference, Springer, Cham. Pp. 171-184.

Hansen, V.E., O. W. Israelsen and G. E. Stringham. 1980. Irrigation principles and practices (No. 04; S613. I75, H3 1980.). New York: Wiley.

Hillel, D. and P. Vlek. 2005. The sustainability of irrigation. Adv. Agron. 87:55-84.

Hussain, S., A. Ahmad, A. Wajid,T. Khaliq, N. Hussain, M. Mubeen, H.U. Farid, M. Imran, H.M. Hammad, M. Awais and A. Ali. 2020. Irrigation Scheduling for Cotton Cultivation. In Cotton Production and Uses. Springer, Singapore. Pp. 59-80.

Irfan, M., M. Arshad, A. Shakoor and L. Anjum. 2014. Impact of irrigation management practices and water quality on maize production and water use efficiency. J. Anim. Plant Sci. 24:1518-1524.

Jeong, K., A. Baten, D.L. Waters, O. Pantoja, C.C. Julia, M. Wissuwa, S. Heuer, T. Kretzschmar and T. J. Rose. 2017. Phosphorus remobilization from rice flag leaves during grain filling: an RNA-seq study. Plant Biotechnol. J. 15:15-26.

Jiang, Q., Y. Du, X. Tian, Q. Wang, R. Xiong, G. Xu, C. Yan and Y. Ding. 2016. Effect of panicle nitrogen on grain filling characteristics of high-yielding rice cultivars. Eur. J. Agron. 74:185-192.

Khan, A., W.A. Shah, Z. Hussain, M. Ahmad, R. Amin, S. Uddin, M. Ishaq, S. Akbar, M. Wisal, S.N. Khan and H. Ahmad. 2020. 24. Analysis of wheat genotypes and N application on the yield in response to protein and nitrogen content in grains and straw. Pure and App. Bio. 9:229-239.

Kumar, R., R.J. Weber and G. Pandey. 2018. U.S. Patent Application No. 10/073,074.

Macintosh, K.A., D.G. Doody, P.J. Withers, R.W. McDowell, D.R. Smith, L.T. Johnson, T.W. Bruulsema, V. O'Flaherty and J.W. McGrath. 2019. Transforming soil phosphorus fertility management strategies to support the delivery of multiple ecosystem services from agricultural systems. Sci. Total Environ. 649:90-98.

Mason, B., M. Rufí-Salís, F. Parada, X. Gabarrell and C. Gruden. 2019. Intelligent urban irrigation systems: Saving water and maintaining crop yields. Agric. Water Manage. 226:105812- 105820.

Novák, V. and H. Hlaváčiková. 2019. Soil as a Part of the Soil–Plant–Atmosphere Continuum (SPAC). In Applied Soil Hydrology Springer, Cham.Pp. 1-13.

Palta, J.A., A.S. Nandwal, S. Kumari and N.C. Turner. 2005. Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer arietinum* L.) subject to terminal drought. Aust. J. Agric. Res. 56:105-112.

Prasojo, I., A. Maseleno and N. Shahu. 2020. Design of automatic watering system based on Arduino. J. Rob. and Cont.1:59-63.

Pratt, T., L. N. Allen, D. E. Rosenberg, A. A. Keller and K. Kopp. 2019. Urban agriculture and small farm water use: case studies and trends from Cache Valley, Utah. Agric. Water Manage. 213:24-35.

Rafi, Z.N., F. Kazemi and A. Tehranifar. 2019. Effects of various irrigation regimes on water use efficiency and visual quality of some ornamental herbaceous plants in the field. Agric. Water Manage. 212:78-87.

Singandhupe, R.B., G.G.S.N. Rao, N. G. Patil and P.S. Brahmanand. 2003. Fertigation studies and irrigation scheduling in drip irrigation system in tomato crop (*Lycopersicon esculentum* L.). Eur. J. Agron. 19:327-340.

Talebpour, A., H.S. Mahmassani and S.H. Hamdar. 2017. Effect of information availability on stability of traffic flow: Percolation theory approach. Transp. Res. Rec. 23:81-100.

Tura, L.E. and T. T. Tolossa. 2020. Systematic review: Effect of Irrigation Water Quality and Deficit Irrigation on Crop Yield and Water Use efficiency. Turk. J. Agri.-Food Sci. and Tech. 8:1201-1210.

Uddin, M.T. and A.R. Dhar. 2020. Assessing the impact of water-saving technologies on Boro rice farming in Bangladesh: economic and environmental perspective. Irrig. Sci. 38:199-212.

Valayamkunnath, P., V. Sridhar, W. Zhao and R.G. Allen. 2019. A comprehensive analysis of interseasonal and interannual energy and water balance dynamics in semiarid shrubland and forest ecosystems. Sci. Total Environ. 651:381-398.

Willy, D.K., M. Muyanga and T. Jayne. 2019. Can economic and environmental benefits associated with agricultural intensification be sustained at high population densities? A farm level empirical analysis. Land use pol. 81:100-110.

Yan, S., Y. Wu, J. Fan, F. Zhang, S. Qiang, J. Zheng, Y. Xiang, J. Guo and H. Zou. 2019. Effects of water and fertilizer management on grain filling characteristics, grain weight and productivity of drip-fertigated winter wheat. Agric. Water Manage. 213:983-995.

Zhang, B., Z. Fu, J. Wang and L. Zhang. 2019. Farmers' adoption of water-saving irrigation technology alleviates water scarcity in metropolis suburbs: A case study of Beijing, China. Agric. Water Manage. 212:349-357.

[Received 20 Jan 2020; Accepted 1 Jul 2020; Published (online) 1 Sept 2020]