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PH Rank
Ph. D. Student, 2- Associate Professor, RARS, Kumarakom, Kerala, India

Vishnu B
College of Agricultural Engineering & Technology, Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
PH Rank
Ph. D. Student, 2- Associate Professor, RARS, Kumarakom, Kerala, India

Pulse drip irrigation: A review

PH Rank and Vishnu B

Abstract
Nevertheless, several studies showed the flooding of root zone due to continuous water application. This review discusses the aspects of pulse irrigation and its various strategies. Pulse irrigation creates favorable condition in crop root zone for better growth of plant. However, creating aeration in root zone helped the plant to enhanced the photosynthesis activity which opened the doors of many researches. Plant roots plays a major role in growth under various conditions. With proper irrigation application the favorable aerated environment can be created. Many researches have been proposed with soil water distribution studies and concluded that aeration in the root zone increases the yield. Thus, the effect of pulse irrigation on various aspects such as crop growth, clogging of emitter, soil water distribution and root zone aeration were proposed by numerous researchers are reviewed.

Keywords: Pulse irrigation, crop growth, root zone aeration, soil moisture distribution, emitter clogging

Introduction
Irrigation is the application of water into the field through different methods and methods used for irrigation purposes includes different application efficiencies and field efficiencies. However, looking to a condition of water availability and conditions of farmers in India the Precise application of water gives better worth to farmers. Whereas Drip irrigation system has also become popular nowadays in India. But the according to Researchers Drip irrigation usually gives water at or near to the root zone of Plant but due to continuous watering the macro pores and micro pores are flooded with water and which regrets the oxygen to enter from plant root to plant and due to this lack of aeration the plant growth also affects. Whereas in other low application of water usually makes the problem of clogging of emitter. To overcome or to the solution of all this problems, Pulse irrigation came into practice. Pulse irrigation applies water in the cycles of irrigation, which gives enough time to aerate the soil and helps in increase of plant growth.

Pulse irrigation also improves water use efficiency when it was used with mulching. Almedia, *et al*. (2015) [3] observed that pulse irrigation saved 25% of water in treatment without mulching and 50% when plastic mulching was used, contributing substantially to improve irrigation water efficiency. Zin El-Abedin (2006) [36] also observed that Pulse drip irrigation increased grain yield by 11.8% compared with continuous drip irrigation. While the total applied, water saved was 2.01% for pulse drip irrigation than that of continuous drip.

Role of pulse irrigation in micro irrigation system
Many researchers studied the pulse irrigation but the initiation was done in 1974. Karmeli and Peri (1974) [19] suggested Pulse irrigation as an irrigation technique achieving a relatively low application rate while using an irrigation device with a higher application rate. Pulse irrigation is composed of a series of irrigation time cycles where each cycle includes two phases, the operating phase followed by the resting or non-operative phase. As a function of the irrigation parameters and the number of cycles in the irrigation, the variables of the pulse pattern, the real irrigation time, the resting time and the total time of a single pulse were defined. A suggested method to determine the number of cycles in one pulse irrigation which in general would be in the range of 5-10 cycles. Fraisse, *et al*. (1995) [12] studied emphasization of conjunctive management of irrigation water and chemicals for both protection of groundwater quality and for optimizing production from limited water supplies. The small plot studies were done with the linear-move irrigation system machine installed at the Colorado State University Agricultural Research, Development and Education Center (ARDEC). Because of the many small plots under the machine it was necessary to control water and chemical applications both along the lateral line and in the direction of travel. Laboratory tests showed that as a means of obtaining a wide range of application rates to plot areas electrical solenoid valves can be pulsed, so long as pulse frequency is less than 1 min.

It was concluded that under pulsed conditions water application was directly proportional to the fraction of time the valve was opened, and that was the viable technique for controlling applications to research plots.
However, the use of continuous irrigation gives the problems of clogging of emitters and loss due to deep percolations of water beyond crop root zone. If applied water is in the cycles of irrigation, it gives an advantage of reducing the clogging and loss due to deep percolation of water and increases aeration in soil. Jackson and Kay (1987) [18] studied that by increasing the emitter size with pulses of irrigation the problem of clogging of emitters can be significantly reduced. An approach to reduce the clogging problem is to increase the size of the waterway in the emitters, this can lead to increased emitter discharge and changes in the soil wetting pattern which may adversely affect water availability to plants. Researchers gave evidence to suggest, however, that established soil wetting patterns can be maintained at the higher discharges if the flow is pulsed. Al-Naeem (2008) [4] experimented the effect of pulse irrigation using high flow rates. Study was conducted with line source on sandy loam soil packed in soil tank. Results showed that increase in pulsed flows up to six times to that of the equivalent continuous flow can be used with little change in soil wetting pattern. The deep percolation of water was reduced and the horizontal spread was increased twelve time to that of continuous flow when pulsed flow was used. Strong correlation was obtained between water application rates and horizontal and vertical advances and that could be expressed as power function. Experiment also gave result that the emitter sizes can increase up to 2.4 – 3.5 times and cross-sectional area of emitter upto 6.0 – 12.0 times than of a normal size to reduce trickle clogging problems. Through Empirical analysis of vertical and horizontal advances, it was seen that both the parameters can be expressed as Power Function.
Researches have been conducted to study and develop some irrigation strategies to save energy on farm and response was positive when it came to pulse irrigation. García-Prats and Guillem-Picó (2016) [14] found that reductions in Emitter discharge, Energy consumption and Energy cost savings are not inherently related to each other.
Pulsed irrigation showed an energy saving potential of 10.67, 6.43 and 6.99% for power capacity, Energy consumption and Energy cost respectively. Elmaloglou and Diamantopoulos (2009a) [9] investigated the infiltration and redistribution of soil moisture under surface drip irrigation considering hysteresis of different textured soils (loamy sand and silt loam). The evaluation of soils was done in terms of wetting front advance patterns and deep percolation under the root zone with the effect of continuous versus intermittent application of 1, 2 and 4 l/h. The soil water retention characteristic curve, evaporation from the soil surface, and water extraction by roots in a cylindrical flow model incorporating hysteresis was used for this purpose. The results showed that, pulse irrigation slightly reduces the water losses under the root zone in both cases (with and without hysteresis) compared with continuous irrigation. Also in both types of irrigation, at the total simulation time, hysteresis reduces significantly the water losses under the root zone. Rank, *et al.* (2019b) [28, 29] performed the automation under pulse irrigation and evaluated the below ground soil water distribution. Aeration was found sufficient under root zone through pulse irrigated soil rather than normal drip irrigated soil.
Finally, the greater effect of hysteresis was found at higher discharge rate (4 l/h) and consequently at higher water content of the soil surface. Skaggs, *et al*. (2010) [33] used numerical simulations and field trials to investigate the effects of application rate, pulsed water application, and antecedent water content on the spreading of water from drip emitters and the simulation results showed that minor increases in horizontal spreading were produced at end of application of water due to pulsing and lower application rates. Primarily due to longer irrigation times, the small increase, however not to flow phenomena also associated with pulsing or low application rates. After a period of 24 hours, the infiltrated water had redistributed which mostly results in disappearing of the small increases. Field trials were matched with the simulation findings, with no statistically significant difference in wetting being found among five water application treatments involving pulsed applications and varying application rates. Nikolidakis, *et al*. (2015) [24] studied the integrated collaborated system for automation with the help of advanced novel routing protocol for Wireless Sensor Networks (WSNs) which named as ECHERP (Equalized Cluster Head Election Routing Protocol).
The historical data and the change on the climate values are taken into consideration for the calculation of irrigation water requirement. In case the collected data changes and is above threshold value then most frequent data collection is proposed to minimize water requirement and in case if change is below threshold value then time interval to collect data increases to save the sensor energy which increases sensor life. Resulted showed that lifetime improved up to 1825 minute and in case of a round of 110 seconds model provides energy efficiency using smaller quantities using ECHERP.
As an efficient means of irrigating small plots, home yards and greenhouses from limited water supplies, without requiring an external energy source realised substantial savings of water and energy, in Bulgaria (Georgiev and Conley, 1996) [15].

Effect of application of pulse irrigation with respect to crop growth

Researchers studied the crop growth with the application of Pulse Irrigation and results compared to the continuous irrigation. Results showed significant effect to crop growth when it was irrigated with Pulses. Levin, *et al*. (1979) [20, 21] studied the soil moisture distribution in a high-yielding apple orchard. With different discharge rate, spacing between tricklers and frequency of application, soil moisture content was determined with three treatments. Results showed that when irrigated twice a week with 8 l/h tricklers the soil moisture and root system distribution covered a wider area than by irrigating daily or once a week with 4 1/h tricklers. Similar root distribution pattern was found in both irrigating daily and once a week but a narrower soil moisture distribution was found with irrigating daily. 17% of the water applied was found water loss by drainage under the trickler.
Pulse irrigation decreased this loss by supplying the water in pace of plant consumption. Assouline, *et al.* (2006) [5] conducted a case study and investigated the combined effects of pulsed irrigation and water salinity on the response of the soil–plant system. Bell pepper (Capsicum annuum L.) was cultivated as a test crop in a screen house and irrigating daily with drip at high frequency with saline and fresh water.
Simultaneous meteorological, physiological, soil physical, plant and soil chemical, and yield data was monitored during the experiment. High water salinity affected most negatively

physiological parameters. During the early stages of plant growth pulsed irrigation led to higher plant weight and leaf area and there was no consistent effect found on the overall season by irrigation frequency. Under pulsed irrigation salinity in the root zone was higher and an observation by leaf chloride content and tensiometer readings indicated that salts from top soil was more efficiently removed by once daily application. Under once daily irrigation with fresh water, yield, fruit weight, and irrigation water use efficiency (IWUE) were highest.

In leaves and fruits, high-frequency irrigation led to higher Mn concentrations and increased concentrations of Cl, N, and P in leaves, confirming earlier conclusions under pulsed irrigation P mobilization and uptake was improved. Abdelraouf, *et al*. (2012) [1] experimented in two fields and studied the effect of short irrigation cycles on soil moisture distribution in root zone, fertilizers use efficiency and productivity of potato. The results indicated that, 3rd cycle under subsurface drip irrigation gives maximum productivity of potato, due to increase in soil moisture distribution and soil moisture content in the root zone after applying short irrigation cycles compared with continuous drip irrigation.

Due to increasing number of pulses inside each irrigation cycle, it causes increase in water movement in horizontal direction than vertical direction hence, increasing in moisture content in root zone and wetted soil volume more than field capacity. Where increasing in wetted soil volume more than field capacity means increasing in volume of available water and nutrients in root zone. By increasing both moisture content in root zone and wetted soil volume more than field capacity in the root zone, these nutrients would be more available for plant. El-Mogy, *et al*. (2012) [10] evaluated the effects on yield and nutritional elements of green beans (Phaselous vulgaris L.) by pulse irrigation. Based on number of pulses irrigation system consists of four irrigation treatments. Results showed that yield was maximum when water was applied in 4 pulses and minimum when water was applied in one time. It was seen that by increasing the number of increasing number of pulses per each irrigation the vegetative growth of green bean plants was improved.

The highest concentration and lowest concentration of all determined nutrient elements was obtained under high pulse irrigation and low pulse irrigation respectively. Phogat, *et al*. (2012a) [26] experimented the pulse and continuous irrigation to almonds through surface drip, and water applications and moisture distribution in the soil were also monitored throughout the season. To evaluate the impact on water balance and salinity distribution in the soil of pulsed application of irrigation, a finite element numerical model (HYDRUS 2D) was used.

The modelled values of moisture content matched well with the weekly measured values with neutron probe at different soil depths (10 cm to 160 cm) with RMSE of mean values varying from 0.01 to 0.08 and 0.01 to 0.05 in pulsing (Ip) and continuous (Ic) treatments respectively. Result showed that simulated seasonal water uptake was slightly higher in pulsing than continuous irrigation, whereas the soil storage was slightly higher under continuous irrigation. The leaching fraction was varying upto 0.25 in both treatments and was higher during August and March – April because of the water requirement of irrigation. The salinity distribution was similar in both treatments and simulated average salinity of soil solution varied from 0.47 to 3.38 dS/m and 0.49 to 3.67 dS/m in Ip and Ic treatments respectively. Hence the modelling simulations revealed that pulsed irrigation at higher discharge rate produced similar water and salinity distribution in the soil as obtained in low discharge continuous irrigation. Phogat, *et al*. (2012b) [25] experimented and verified water and salinity distribution during the profile establishment stage of almond under both pulsed and continuous drip irrigation. Under both irrigation scenarios model simulated values of water content were compared with neutron probe measured values.

Model closely predicted total salts in the root zone which was indicated by correlation with meaured values. Change in soil water salinity and soil water content were simulated by HYDRUS-2D in both wetting pattern and flow domain. Initially salinity was decreased in both pulsed and continous irrigations and soil profile as a function of irrigation was mathematical described best by power function under both irrigation systems.

Higher leaching was found in pulsed irrigation than in continuous irrigation with same amount of water applied. On the basis of crop evapotranspiration (ETc) when irrigation was applied daily with a suitable leaching fraction pulsing influence on soil water content, salinity distribution, and drainage flux was completely vanished. Eid, *et al*. (2013) [7] experimented and studied the effect of pulse drip irrigation and mulching systems for saving water, increasing and improving yield of soybean. The factors that were considered were Pulse drip irrigation technology and mulching systems. The parameters to evaluate the effect were Soil moisture distribution in root zone, Growth characters of soybean plant, Yield of soybean, Irrigation water use efficiency of soybean, Oil content and oil yield, Protein content and protein yield and some Economical parameters.

According to the economical view and the results of statistical analysis for effect of pulse drip irrigation and mulching systems on yield, quality traits and Irrigation water use efficiency of soybean indicated that, with using Black Plastic Mulch and applying the irrigation requirements on 8 pulses/day is the best conditions because these conditions gave the highest value of yield, quality traits and Irrigation water use efficiency of soybean.

Through pulse irrigation techniques water movement in horizontal direction increases than vertical direction and will result in improves soil moisture distribution and wetted soil volume in root zone. Traits of applying irrigation requirement on 12 pulses/day were decreased by increasing of pulses, this may be due to irrigation water was very small with every pulse at applying irrigation requirement on 12 pulses/day and in addition increasing the total time of time-off, this mean, insufficient application for irrigation water to remove water stress in the root zone. Phogat, *et al*. (2013) [27] investigated the use of HYDRUS-2D simulations conducted on field for a full grown surface drip irrigated almond orchard over a season.

Daily fluctuation of water was evaluated by model under full pulsed, sustained deficit pulsed and full continuous irrigation. Assessment of pulsing impact on water flux dynamics was also seen. In the sustained deficit pulsed treatment, 65% of calculated crop evapotranspiration (ETc) was replaced by applied water, compared to replacement of 100% ETc in the other two treatments. Efficiency of water uptake under sustained deficit pulsed was higher compared to full water application conditions (full pulsed and continuous irrigation). Non-productive water fluxes were largely contributed by higher irrigation amount under full pulsed and continuous irrigation. For all treatments during the growing seasons for yield reduction, the average modelled soil solution salinity of the profile remained below the threshold.

Under pulsed and slow discharge continuous irrigation seasonal water uptake by almonds remained almost on par indicates that the pulsing did not provide any additional advantage, although it is an alternative to slow discharge continuous irrigation. Under sustained deficit irrigation, irrigation water productivity increased substantially, yield was increased by 8% and about 35% of irrigation water was saved compared to full irrigation. For almond cultivation region with severe water scarcity sustained deficit irrigation appears to be a promising deficit irrigation strategy and irrigating almonds above the sustained deficit irrigation may enhance unproductive water usage in the form of accelerated drainage, which may lead to potential danger of migration of nutrients and solutes to the groundwater, thereby posing a threat to the quality of groundwater and receiving surface water bodies. Maller, *et al*. (2016) [22] studied and verified that the effects of pulse irrigation on cucumber plants which were subjected to either water deficit or were sufficiently supplied with water and by considering the hypothesis that the water application during times when evapotranspiration demand is greater than that will promote benefits to the crop compared with the continuous irrigation in the early hours of the day.

Designed used was completely random and treatments were distributed in 3 × 4 and 4 × 4 factors in the first and second respectively, while the replenishment of the irrigation depth relative to the crop evapotranspiration was the first factor and the number of pulses was the second factor. The first and second cycles there were total 48 and 64 plots respectively. For first and second cycles the application of treatments were started in the vegetative phase and in the reproductive phase respectively. It was concluded that smaller irrigation depths than the crop requires can be applied by pulses without resulting in a reduction in the vegetative growth in Japanese cucumber. Several experiments have shown positive responses in some crops to high frequency drip irrigation (Freeman, *et al*., 1976; Segal, *et al*., 2000; Sharmasarkar, *et al*., 2001) [31, 13, 32].

Effect of pulse drip irrigation on soil water distribution

Researches showed that from the upper half of the plant root zone approximately 70% of water used by plants is removed. When soil – water tensions in this area kept below 5 atmospheres optimum crop yields resulted. Root penetration can be extremely limited into dry soil, a water table, bedrock, high salt concentration zones (Elwin, 1997) [11]. Levin, *et al*. (1979) [20, 21] concluded for his research that the pulse treatment can replace the advantageous low (1 liter/hour) discharge rate to a large extent avoiding the difficulties of blocking of outlets by maintaining a higher (2 liter/hour) discharge rate. Study was to compare results between laboratory and field experiments for prediction of soil mositure distribution from point source trickle and computerized simulation model. However, both computed and experimental data were in good agreement.

Under point source trickle when continuous water was applied 26% loss of total amount applied was found for 1 lph whereas 2 lph pulsed flow resulted in only 12% loss. The lateral distribution of water for continuous irrigation 80% of the water in the wetted soil volume was distributed 45 and 43 cm horizontally where as in pulsed treatment distribution was to 29 and 40 cm after 12 to 24 hours respectively. Rank, *et al.* (2019a) [28, 29] studied the soil water distribution under line source and point source which stated that the soil water distribution lacked the aeration for proper root growth of the plant under both point and lie source. With not significantly affecting the horizontal distribution pulsed treatments showed a clear advantage in reducing water loss under the root zone. Mostaghimi and Mitchell (1983) [23] conducted laboratory experiments to study the effect emitter dicharge rate of trickler on the distribution of soil moisture in silty-clay loam soil.

A simulated model was used to predict soil moisture distribution pattern and was used to evaluate laboratory results. For both pulsed and continuous irrigation treatments soil moisture distribution was studied and results showed good agreement between predicted and measured values. As increasing the trickle discharge rate resulted in decrease in horizontal component whereas increase in vertical component of wetted soil profile. The water loss below root zone was found significantly less in pulse irrigation compared to the continuous. Pulsed applications rates can replace continuous small discharge rates to reduce irrigation water runoff problems on heavy soils and with restricted infiltration allow the use of larger emitter orifices to decrease potential clogging of the trickle system. Goodwin and Boland, (2001) [16] studied deficit irrigation scheduling for optimistic water use efficiency and indicated that on Israeli sandy loam soils, within the first 30 cm the main root zone had been found under pulse irrigated citrus, which results in uneven distribution of root zone temperatures as upper layer soil temperatures will increase more quickly in spring than in the lower parts of the soil. Bouma, *et al*. (2003) [6] showed that vapour pressure deficit about the trees was reduced by pulsing irrigation in a consistent trend. To reduce water stress within the tree pulsing irrigation regime is effective.

Researches from USA and Israel provided evidence that productivity and water saving improvements were provided by Open Hydroponic principle of maintaining soil moisture as close as possible to field capacity. In sandy soils when soil moisture levels fall below field capacity trees begin to experience water stress. In order to replenish soil moisture supplies near the root more quickly than with lower soil moisture contents, higher movement rates of water or hydraulic conductivity of the soil is found at higher soil moisture contents.

Applying irrigation water in pulses rather than giving it at one time can save or prevent from losses by giving enough time to media to moisten and hence allowing it to absorb subsequent irrigation more readily and reducing the total amount of water required. Scott (2000) [30] experimented four different areas irrigated for one hour each and hence four hours of total time, and result showed that a 25% reduction in water usage was obtained along with the adequate wetted container media by irrigating each area sequentially for 15 minutes intervals and repeating this process twice. The system becomes easy when it is automated with solenoid valves and thus labour cost is reduced, required to turn various zones on and off.

Due to narrow paths of water which gives small discharge, the problem of emitter's clogging in sandy soil for continuous drip irrigation system was major and depth of wetting pattern was relatively higher than the width, thus causes deep percolation beyond root zone. The information on depths and widths of wetted zone of soil plays the greatest role in design and management of drip irrigation system and there is a lack of models to predict wetting pattern under pulse and intermittent flow regime, since the applicability of the available models were limited to continuous flow regime only. Ismail, *et al*. (2014) [17] researched and developed a dimensional analysis model to estimate both depth and width of wetting pattern under different flow regimes.

Semi – empirical approach and dimensional analysis method was used to develop a model for determining geometry of wetted root zone. Results which were predicted values were compared to those obtained through laboratory experiments conducted in same soil. After 1, 2, 3, 4 hours of water application maximum depths and widths of wetted zone were determined under different flow regimes. Model performance was found good on the basis of root mean square, mean error and model efficiency parameters and concluded that to predict wetting pattern under continuous, intermittent and pulse flow with line source of water application developed models can be used.

Pulse flow results showed that the wetted diameter increased and wetted depth decreased as the operating on-time decreased for the same amount of applied water. Deep percolation was reduced and horizontal spread increased as the pulsed flow was increased from six to twelve times the continuous flow. This result showed the advantage of pulse flow, for reducing the deep percolation of water under the crop root zone, while obtaining a wide horizontal spread of wetting. This enabled use of a highly discharge emitter with the same amount of water. Wetting Pattern is mostly influenced by soil hydraulic properties, trickle discharge rate and irrigation frequency as these factors are not adequately incorporated in the design of trickle system. Elmaloglou and Diamantopoulos (2007) [8] studied that factors influencing on wetting front advance and on the water losses by deep percolation under the root zone for surface trickle system. The evaporation from soil and water extraction by plants root were incorporated to introduce a cylindrical flow model. Results showed that, for pulse irrigation the vertical component of wetting front was greater than for continuous irrigation in both type of soil for which study was conducted with two discharge rates and for equal irrigation time duration.

Mulching also affects wetting pattern as researchers have found significant difference of wetting front under mulch and non-mulch condition with trickle irrigation system. Zhou, *et al*. (2017) [35] found that under low frequency irrigation soil moisture was most affected by mulch coverage (full or half surface coverage) whereas under high frequency irrigation soil moisture was most affected by lateral spacing (adjacent to or between crop rows).

Effect of pulse drip irrigation on clogging ratio of emitters

The emitters likely to clog depends on mostly cross-sectional area of flow channel amount of turbulence in the flow channel. A large cross section allows flow to pass freely without clogging and highly turbulent channel allows dirt particle in suspended form while passing through emitter. Yardeni (1989) [34] found that Pulse irrigation itself can increase the resistance to blockage in trickle irrigation and that permits to avoid bulky and costly filters. Pulse irrigation ensures more uniform irrigation over whole cycle. Use of larger emitters in drip irrigation was an effective solution to avoid clogging. Al-Amoud and Saeed (1988) [2] proposed that to maintain application rate, system should be operated in pulses rather than continuously. Jackson and Kay (1987) [18] demonstrated that with small change in wetting pattern pulsed flow with three times the continuous flow can be used with reduced tendency to clog and allowing a significant increase in emitter sizes.

Summary and Conclusion

Various studies for pulse irrigation were approached across the globe in early 70’s – 80’s. Though in between some years pulse irrigation was not much popular but in recent years when the aeration in irrigation water came into the picture, pulse irrigation gained popularity. Pulse irrigation plays very good role in crop production. The pulse irrigation is aimed at achieving a lower rate of application which permits proper aeration in the root zone from a higher application rate irrigation emitter.

Metabolites, ethylene and carbon dioxide may get trap in saturated soils in the root zone and the concentrations of this can seriously affect the rate of growth and size of the plant. There are many aspects that are affected by pulse irrigation. So the effect of pulse irrigation on crop growth, root zone aeration, clogging ratio of emitter and soil water distribution in the soil need to get studied. The review was performed for every aspects and were briefly offered in the article.

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