Studies on Hydraulic Performance of Furrow Irrigation to Optimise Design Parameters Suitable to Onion Field in Hawassa, Ethiopia

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Abstract

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Ground water is a scarce and expensive resource which needs to be utilized in a highly productive manner for agriculture. Inefficient use of ground water by surface irrigation will result in soil salinization in the long run. This demands precise application of required irrigation water with high efficiency. Furrow irrigation is most widely used among the surface irrigation methods. Furrow design parameters are inflow rate, the length of the run in the direction of the flow, the time of irrigation cutoff and soil infiltration characteristics. These parameters have been studied in order to design an optimum furrow length to achieve maximum application efficiency. Time ratio, which is defined as the ratio of the time required for infiltration of net amount of water needed for the root zone to the time when the water front reaches the end of the run, plays a key role in determining optimum furrow length to achieve maximum irrigation efficiency. In this study, using established model parameters, optimum time ratio and furrow length for maximum application efficiency in furrow irrigation were determined. The model was established from field tests conducted on onion grown furrows, 0.4 m wide and 70 m long, with two existing slopes 0.2 and 3% and each slope had three different inflow rates (0.3, 0.9, 2.7 L/s; 0.4, 0.7, 1.1 L/s respectively). Inflow rate of 0.3 L/s was very low for 0.2% slope in moderately permeable soil resulting long advancing time and less application efficiency. Under open end furrows, maximum attainable efficiency was 54.2% and the optimum furrow lengths to realize this efficiency were 32 and 74 m for 25 and 60 mm irrigation depth with 0.3L/s inflow rate. It was concluded that at higher slope of 3%, increase in the flow rate beyond 0.7L/s cause decrease in optimum length for the maximum attainable water application efficiency. When runoff is eliminated or reused, the maximum attainable efficiency of 75.9% and 71.1% can be achieved with 0.4 L/s and 0.9 L/s in 3% and 0.2% slope, respectively. For furrow slope 0.2%, peak irrigation demand of 3mm/day and a recommended furrow discharge of 0.9 L/s, suitable furrow length is 106 m length to have advance time of 10.7 min and 21.3min as total irrigation time to apply 40mm irrigation water for irrigation frequency of 7days. Optimum time ratio under different in flow rates for various irrigation depths reveals that for optimum furrow length and maximum application efficiency, the advance time should be two quarter of the total irrigation time.

Keywords: Furrow irrigation advance; optimum time ratio; irrigation efficiency; uniformity

INTRODUCTION

Background

On a global basis, 69% of all water withdrawn for human use is currently consumed by agriculture, most in the form of irrigation (UN/WWAP, 2003; Prinz 2004) with very low use efficiency (30-40%). Surface irrigation methods having relatively lower water use efficiency when compared to the pressurized systems are responsible for this. Surface irrigation is widely practiced throughout the world, more than 95 % of world's irrigated area (UN/WWAP, 2003). Even in industrialized countries, for instance in the U.S., the area devoted to surface irrigation is still well over 70% (Playan *et al.* 2004). In Ethiopia irrigation efficiencies are generally low, of the order of 25 to 50%, and problems with rising water tables and soil salinisation are now emerging (EARO 2002). As the world is running into a very serious water crisis in this century (Shiklomanov, 2000; UN/WWAP, 2003), increasing water use efficiency in irrigation may be the most appropriate way of preserving our precious water resources since even 10% saving in agriculture is more than enough to meet all domestic use (Postel, 1997). Therefore, the ultimate objective of irrigation systems, especially surface irrigation, design should achieve maximum irrigation efficiency with a minimum cost.

Furrow irrigation is most widely used among the surface irrigation methods. It is designed on the basis of soil, crop, topography, size and shape of the irrigated area. A furrow irrigation system has several design variables that affect its performance. These are the inflow rate, the length of the run in the direction of the flow, the time of irrigation cutoff and soil infiltration characteristics. These parameters have been extensively studied by many authors in order to design an optimum furrow to achieve maximum application efficiency. The inflow rate design, which is affected by the slope, the length of the furrow and the intake rate of the soil, can be adjusted by the designer to achieve a good uniformity and to irrigate to the required depth in a reasonable time. Water application efficiency is influenced principally by the amount of water applied, the intake characteristics of the soil and the rate of advance of water in the furrows (Jurriens and Lenselink, 2001).

Optimal furrow length and irrigation cutoff can be determined, as related to soil infiltration characteristics, by the time ratio (ratio between the time required for infiltration of total amount of water required for root zone and the time when the water front reaches the end of the run) to achieve maximum application efficiency (Holzapfel*et al.,* 2004). It is true that the optimum furrow length where the maximum application efficiency can be achieved, changes with respect to the irrigation depth applied. But the maximum efficiency itself is a constant since it is affected by the infiltration function and advance function only.

In this study, a mathematical model was developed using hydraulics of surface irrigation to find out optimal time ratio to prove maximum application efficiency, tested in onion grown furrows and extrapolated for different field conditions may be the most appropriate way of preserving our precious water resources. Therefore, the ultimate objective of irrigation systems, especially surface

irrigation, design should achieve maximum irrigation efficiency with a minimum cost.
Ground water is still an untapped water resource for agriculture in Hawassa and not exploited to its full potential. The main constraint is heavy investment and economic feasibility for irrigated agriculture. In most irrigable lands, horticultural crops in general and vegetables in particular, play an important role in contributing to the household food security. The vegetable being cash crop with nutritional value generate income for the poor households. Higher profits can be achieved by increasing the production of a particular vegetable throughout the year when efficient irrigation system is used. This can justify the investment cost of tapping ground water. In Ethiopia, currently onion covers about 17,980 ha. Ethiopia has a great potential to produce onion every year for both local consumption and export. Due to such an important contribution of onion to the country, the proposed research will make some efforts for its promotion to year round cultivation and enhance land productivity.

Statement of the Problem

In the study area, onion is cultivated in limited area throughout the year where stream/lake water is available for supplemental irrigation. To cultivate onion throughout the year supplemental irrigation is needed during dry season. Ground water is one of the alternate sources available for irrigation but needs to be tested for its feasibility. In the University farm, furrow irrigation is practised in a non productive manner. Furrows are not constructed with suitable slope and the system is not operated with optimum discharge resulting waste of expensive ground water and induced soil erosion. Moreover, there is also a danger of land productivity in the long run if the present practice of irrigation is continued inefficiently. It demands for efficient application of irrigation water by appropriately manipulating inflow rate, slope, furrow length and irrigation time for improving the application efficiency. The constraint is lack of knowledge database providing information about optimum furrow length and irrigation time to maximise application efficiency for different land slope and soil texture conditions in Hawassa.

This study has been undertaken to study hydraulic performance of furrow irrigation in onion cultivation and reveal optimized furrow design parameters for maximum application efficiency. In furrow irrigation, the issue of infiltration variability and its influence over performance and management of surface irrigation are important. Uniformity of water application totally is dependent on the multitude of the complex soil properties over which the operator or the designer has no control. So the site specific hydraulic behavior of the furrow irrigation needs to be studied for better design and operation. The proposed study will bring out optimum design and operation parameters of the furrow irrigation suitable to the experimental area.

Justification

The Ethiopian Government has committed itself by including water as one of its national priority agenda and formulated a

15-year comprehensive Water Resources Development including small scale irrigation in the sustainable development and poverty reduction programme. The proposed research project falls in line with the Ethiopian government policy to develop the subsector to fully tap its potentials by assisting and supporting farmers to improve irrigation management practices and the promotion of modern irrigation systems, (Teshome A. 2006).

Research Hypothesis

Time ratio is crucial to regulate application efficiency. Furrow slope influences uniformity of application.

Objectives

The proposed research has general objective to study hydraulic performance of furrow irrigation with the following specific objectives to resolve the identified problems of rain-fed farming of onion cultivation.

1. To investigate time ratio under different flow rates and furrow slopes to optimize irrigation performance while accounting for spatial variation of soil characteristics.

2. To recommend optimum furrow length and advance time under varied application depths.

METHODOLOGY

Theory of Irrigation Model

Furrow irrigation system has several design variables that affect its performance. These are the inflow rate, the length of the run in the direction of the flow, the time of irrigation cutoff and soil infiltration characteristics. Optimal furrow length and irrigation cutoff can be determined, as related to soil infiltration characteristics, by the time ratio (ratio between the time required for infiltration of total amount of water required for root zone and the time when the water front reaches the end of the run) to achieve maximum application efficiency. Optimum furrow length changes with respect to the irrigation depth applied. But the maximum application efficiency itself is a constant since it is affected by the infiltration function and advance function only. In this study, a mathematical model is fitted for the study area using hydraulics of surface irrigation to find out optimal time ratio to prove maximum application efficiency as below and tested in onion grown furrows.

Both the infiltration depth and water advancement on soil surface in furrow irrigation are a function of irrigation time. This relationship is known as advance function expressed in empirical form as described by Hart *et al*. (1968):

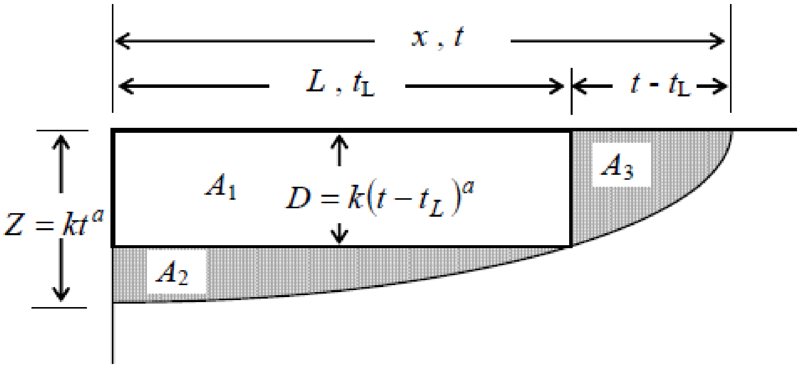

Fig. 1 Infiltration pattern through furrow length**.**

In Fig. 1, L: furrow length; D: required depth of irrigation to satisfy the rootzone; *k* and *a*: infiltration parameters; *t*: opportunity time; t_L: time required for the water front to reach the lower end of the furrow.

The irrigation water delivered per unit width that is furrow spacing (*W*), is distributed in V_1, V_2, and V_3 where V_1: total volume of water required for the root zone represented by A_1; V_2: deep percolation loss represented by A_2; V_3: volume of runoff flowing out from the downstream end of furrow having a length *L* represented by A_3.

$$L = a\,t^b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where L is the length covered by water at time *t* (m), *t* is the total water application time (min), *a* and *b* are the empirical constants of advance function (Elliot *et al* 1982). Cumulative infiltration depending on the infiltration opportunity time may be explained by Lewis (Kostiakov) Equation (Bassett, 1972):

$$Z = c\,t^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where, Z is the cumulative infiltration depth (mm), *t* is the lapsed time (min), *c* and *n* are the constants for a given soil at a particular moisture level. The time available for infiltration or opportunity time at any point along the furrow must be known in order to design a furrow precisely. The opportunity time for infiltration (t_i) at section *s*, along the furrow at a given time *t* is given by,

$$t_i = t - t_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where t_s is the advance time at a given section.

$$\text{Application efficiency } E_a = \frac{X^b(1-nX)}{1-nb/(1+b)} \text{ ------------- } (4)$$

Where, X = Time ratio of advance time to total irrigation time

Optimum time ratio, $X_{opt} = {}^{b}\!/_{n}/(1+b)$ ------------------------------- (5)

From irrigation scheduling, required depth of irrigation water which is to be infiltrated at the downstream of the furrow (D_L). Total irrigation time is calculated by the formula below.

$$D_L = cT^n(1-X)^n$$ -- (6)

Irrigation evaluations were performed in onion field located in research farm of Hawassa University. Optimal furrow length and irrigation cutoff can be determined, as related to soil infiltration characteristics, by the time ratio (ratio between the time required for infiltration of total amount of water required for root zone and the time when the water front reaches the end of the run) to achieve maximum application efficiency (Holzapfel *et al*., 2004). Mathematical model was established using hydraulics of surface irrigation to find out optimal time ratio to prove maximum application efficiency, tested in onion grown furrows. Uniformity of application (C_u) is determined from

$$C_u = (1 - \frac{\sum d}{nX})100$$

Where, d - numerical deviation of water depth from average application depth

X - water depth applied at each station

n - number of stations along the furrow

Experiment

The research was conducted at research farm of Hawassa University, located in the outskirt of Hawassa city to represent the hydro climatic conditions prevailing in SNNPR which needs alternative techniques to cope with dry season and improve land productivity in onion cultivation by promoting year round cultivation using ground water. Experiments were conducted to test the model in field plots prepared specifically for this research. Soil texture was sandy loam with average bulk density of 1.77 g/cm^3 and 120mm/m available water holding capacity taken from FAO standard. For the root zone depth of 0.4m and 50% depletion level, 24mm of water is to be replenished by irrigation sufficient for eight days. The furrow inflow rate and duration of irrigation was decided considering 50% depletion level. The research field was first leveled and two plots were formed with the slopes of 0.2 (plot A) and 3 (plot B) %. Then three furrows with 0.3 m width and 70 m length were constructed on each plot with three replications. Onion seedlings were planted on the furrows in 21st July, 2013 and six irrigations were applied during crop period when soil moisture depletes 40% of available water. Existing tube well was used to supply irrigation water. The inflow rates were 0.3, 0.9 and 2.7 L/s to plot A and 0.4, 0.7 and 1.1 L/s to plot B. The rates were measured volumetrically and maintained stable during the irrigations. Measurements were done only on the middle furrows of each plot to eliminate the side effects. Stations with 10 m intervals were marked along the side of the furrows to investigate the water advance and recession speed. The time elapsed, both, for the advancing water front to reach to each station after the application from the top end of the furrow and the recession from the station were recorded. Then, parameters *a* and *b* in advance equation were computed for each slope and application rate using Curve expert software with these recorded data. Similarly, parameters *k* and *a* in infiltration equation were determined from the double ring infiltrometer method. Irrigation time was decided through examining the moisture deficit in the soil profile up to 0.4 m depth gravimetrically. Actual quantity of irrigation water applied varied depending on limitations of flow rate control and furrow slope. Although the length of the furrows were made 70 m, time ratio and irrigation efficiencies were calculated for the furrow lengths of 20, 40, 50, 60 and 70 m for each of the three slope and inflow rate. Noting t_L (the time elapsed for the advancing water front to reach to a particular length or station), t-t_L (the time required for the net amount of water to infiltrate fully), and X (time ratio), the irrigation efficiencies were calculated. Optimum furrow lengths and maximum application efficiencies were also calculated. Soil Texture analysis, bulk density and basic Infiltration rate, were measured for the experimental plots. The geometrical and hydraulic characteristics of the furrows are noted.

Fig 2 Field experiments

Meteorological Data

Crop water demand was calculated from climate data using CROPWAT software. Rainfall, temperature, humidity, solar radiation and wind velocity data obtained from Meteorological station of Hawassa were used to arrive at irrigation demand.

RESULTS AND DISCUSSION

Irrigation demand

The experiment to study the furrow hydraulics was conducted in November and December when the rainfall was less and the crop water demand was met mostly by irrigation. Effective rainfall was 351mm and total irrigation demand was198 mm. Peak irrigation demand was 2.9 mm/day in November. Since adequate rainfall occurred in July, August and September, irrigation demand was low (Fig. 3, 4). Total crop water demand was 459 mm of which 43% needs to be met by supplemental irrigation and the rest is contributed by rainfall.

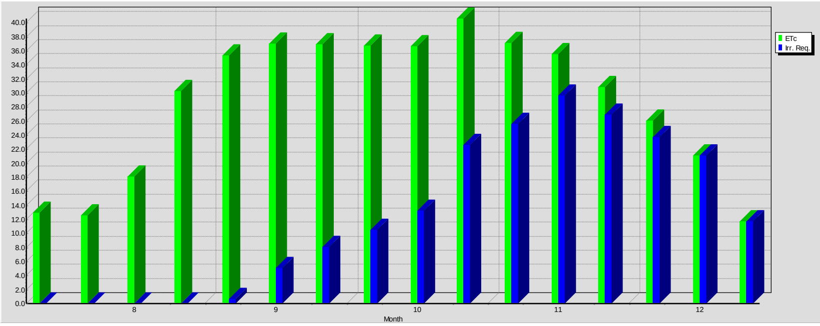

Fig. 3 Crop water and Irrigation demand of Onion

Depending on flow rate and furrow slope the quantity of water applied in each irrigation event varied due to field restrictions. In plot A, depth of applied irrigation water was 27, 18 and 17 mm under flow rate of 2.7, 0.9 and 0.3 L/s, respectively, whereas in plot B, it was 15, 39 and 27 mm under 1.1, 0.4 and 0.7 L/s respectively. This permitted to have irrigation interval of 5 days to a maximum of 13 days. Discharge of 1.1 and 2.7 L/s does not provide opportunity to apply more irrigation water under slope of 3 and 0.2% respectively. Discharge of 0.4 L/s allows higher irrigation water depth in 3% furrow slope (plot B). These slopes are existing in the farm and furrow irrigation has not been practiced with suitable flow rates in these slopes resulting soil erosion and damage of furrows. This also results in wastage of water as surface runoff going out of the field. With high flow rate of 4 L/s, water was applied in the interconnected furrows and irrigation was done in unorganized manner in the existing pattern followed in the farm way due to lack of training. Three such irrigations were done with duration of 1 hour per irrigation. From fourth irrigation to 10th irrigation event, irrigation flow rate was done in controlled manner in plot A and plot B as per the flow rates mentioned above

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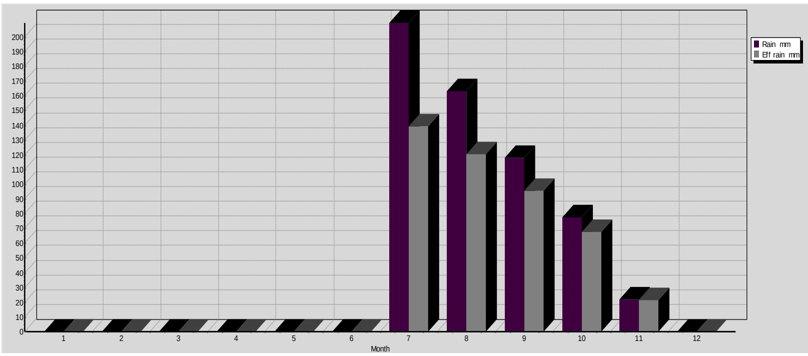

Fig. 4 Rainfall and effective rainfall during the experiment

Infiltration and Advance Characteristics

Water advance and infiltration parameters obtained from the experiments are presented in Table1. *Fitted Infiltration function* $Z = 5.987\, t^{0.807}$

Table 1 shows that parameters a and *b* are in nonlinear relation to the inflow rate whereas these are directly proportional to inflow rate as reported by Konukeu *et al* (2006). Some deviation occurred may be due to variability of soil texture and error in construction of uniform bed slope. The water application efficiency strongly depends on parameters b and n in advance and infiltration functions. These two parameters reflecting the hydraulic behavior of the soil and the maximum application efficiency also depends on the magnitude of these parameters.

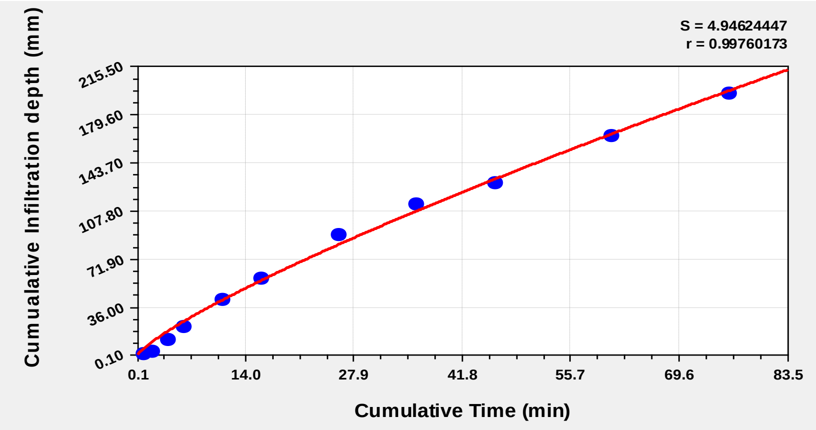

Fig. 5 Cumulative Infiltration curve

Correlation coefficient of 0.99 indicates the fitted power function strongly relates cumulative infiltration with cumulative time with standard error of 4.95mm which is less than 10% of normal water application depth of 50 mm in surface irrigations. A variation of 10% in irrigation water application depth is allowable as a design guideline. From 10 to 40minutes of cumulative time the deviation is positive and in the beginning and after 40minutes the deviation is negative (Fig.5). It implies that when we use the model to schedule irrigation time between 10 to 40minutes, there is a possibility of over irrigation due to positive deviation.

Table 1 Infiltration and advance parameters with slope and inflow rate

Furrow	Slope %	Inflow rate, (L/s)	Infiltration parameters		Advance parameters	
			c	n	a	b
A	0.2	2.7	5.987	0.807	22.1	0.933
		0.9			20.91	0.685
		0.3			7.56	0.764
B	3	1.1			19.66	0.796
		0.7			6.63	0.887
		0.4			8.77	0.467

The infiltration parameters and the Manning roughness coefficient are critical variables in the design and evaluation of surface irrigation systems (Mailapalli *et al*., 2008; Rodríguez and Martos, 2010). Their values vary during an irrigation event, and the estimation of advance and recession times using constant values may lead to considerable errors. Such errors will result in inaccurate design of furrows resulting expensive water loss. To minimize such errors incorporation of infiltration parameters in the furrow design is inevitable. In the present study most of the irrigation events occurred in the second half of the crop period due to insufficient rainfall. Thus infiltration parameters measured in that period will be more relevant for the design of furrows suitable for the study area. In such case inflow – outflow will be more appropriate rather than double ring infiltrometer. So, further improvement is possible if infiltration parameters are measured more accurately. Moreover, infiltration property depends on soil condition and crop characters such as root penetration and distribution. Being a shallow rooted crop yielding bulb in the top soil, it will have an influence on soil infiltration. This influence can also be well considered in the measurement of soil infiltration and incorporating the infiltration parameters in the furrow evaluation and design.

Time Ratio and Application Efficiency

At a specific slope and inflow rate, the time ration, *X*, will decrease with increasing furrow length since t_L increases. For any given furrow length, either increasing inflow rate with a constant slope or increasing slope with constant inflow rate will increase t_L and thereby X value. This means that changes in the furrow lengths and inflow rates will ultimately influence the water application efficiency (Table 2). Therefore, a well-balanced design of these three variables (inflow rate, slope and furrow length) may lead the designer to a maximum efficiency. Mathematical analysis showed that the time ratio (*X*) was the factor for this well-balanced design. Generally, efficiency increases with decreasing *X*-value. However, for a particular inflow rate, this increase is not continuous but starts decreasing after certain *X*-value (Table 2). After reaching 0.47 there is no appreciable change in application efficiency. Maximum application efficiency of 55% was obtained with flow rate of 0.9 L/s for 0.2% slope at 60 m furrow length whereas in case of 3% slope, the maximum of 53% application efficiency was obtained with flow rate of 0.4 L/s. After 50 m furrow length the increase in application efficiency is not highly significant. Time ratio plays significant role in increasing the application efficiency until certain length.

Table 2. Influence of furrow length, slope and inflow rate on water application efficiency

Slope %	Flow rate, L/s	Furrow Length, m									
		20		40		50		60		70	
		X	E_a	X	E_a	X	E_a	X	E_a	X	E_a
	2.7	0.2	31	0.37	45	0.48	50	0.57	52	0.68	52
0.2	0.9	0.14	34	0.29	49	0.4	54	0.47	55	0.6	54
	0.3	0.16	33	0.32	48	0.42	52	0.47	54	0.5	54
	1.1	0.16	32	0.33	47	0.41	51	0.52	54	0.51	54
3	0.7	0.18	30	0.43	50	0.58	53	0.65	52	-	-
	0.4	0.15	49	0.64	53	-	-	-	-	-	-

X – Time ratio, E_a – Application efficiency

According to Arbat (2011) when the time ratio was below 1 the irrigation performance indices were improved and this conforms to the results obtained in the present study. Soils suffering from surface crust or fine structure have the highest water loss potential due to evaporation from the large wetted surface area and runoff (Al-Qinna and Abu-Awwad, 1998). So, selecting the suitable flow rate is important to enhance vertical water penetration and to reduce wetting soil surface, thereby lessening water loss by evaporation and runoff. In 0.2% slope significance difference found at p value of 0.01. Flow rate of 0.3 and 0.9 L/s can be grouped together and performed well in terms of application efficiency followed by 2.7 L/s. Coefficient of variation of data is 1.42; standard error of deviation is 0.58% with critical difference of 1.62%. At 3% slope no significant difference was found among the furrow flow rates. Rodríguez (2003) reported that constant versus variable inflow can affect the estimation of infiltration parameters in furrow irrigation and thus the design parameters. Practicing variable flow rates instead of keeping it constant during irrigation can also be an option to maximize water intake and reduce runoff or ponding in the downstream of the furrows. The pattern of varied flow rate will depend on slope since poor intake will result in the upstream when slope is increased.

Optimum Furrow Length and Maximum Application Efficiency

Using the parameters obtained in the field experiments, calculated *X* values to realize maximum efficiencies, furrow lengths to achieve these efficiencies and some other elements of calculations are summarized in Table 3, Fig 5 and 6. Generally at any given slope, increasing inflow rate (Table 3) leads time ratio to decrease as seen in 3%. This is not true in case of 0.2% slope at 2.7 L/s flow rate where the time ratio increased with increase in flow rate due to less depth of application. Because of high flow rate, it was not possible to apply more depth due to runoff and flow was cutoff as soon as water front reaches the end of the furrow. Therefore, the maximum efficiency and furrow length to provide this efficiency will increase while inflow rate increases at the same slope facilitating higher total irrigation time resulting less time ratio.

Table 3 Optimum time ratio and maximum efficiency

Slope	Flow rate, L/s	Optimum time ratio	Maximum pplication efficiency, %
3%	1.1	0.549	53.8
	0.7	0.582	52.9
	0.4	0.394	59.4
0.2%	2.7	0.598	52.5
	0.9	0.504	55.2
	0.3	0.537	54.2

The value of 0.8 as infiltration power factor ‘n’ points that the infiltration rate of the soil is moderate since it approaches close to 1. Irrigation efficiency was medium for this kind of soil since there will be considerable deep percolation and surface runoff losses. In 3% slope, maximum efficiency of 59.4% is obtained at optimum time ratio of 0.394 whereas in 0.2% slope 55.2% is obtained at time ratio of 0.504. This indicates that for getting maximum application efficiency the time ratio should be minimum for the given slope and flow rate. To achieve this furrow length should be shortened to reduce the advance time or increase the total irrigation time i.e in each irrigation as for as possible apply more depth of irrigation water.

From Fig. 6, it is clear that maximum application efficiency of 59.4 was obtained at 0.4 L/s in 3% slope and 55% occurred at 0.9 L/s in 0.2% slope. Inflow rate of 0.3L/s was very low for 0.2% slope in moderately permeable soil resulting long advancing time. Flow rate of 0.3 L/s results higher time ratio low application efficiency in 70 m furrow length with 3% slope. Under open end furrows, maximum attainable efficiency was 54.2% and the optimum furrow lengths to realize this efficiency are 32 and 74 m for 25 and 60 mm irrigation depth with 0.3 L/s inflow rate whereas maximum efficiencies were 55.2% and 52.5% and corresponding optimum furrow lengths were 71 & 149 m and 167 & 46 m for 0.9 and 2.7 L/s inflow rates, respectively, when the slope was constant at 0.2%. This implies that, at a certain slope, maximum efficiency for a particular furrow length is achieved applying the optimum inflow rate.

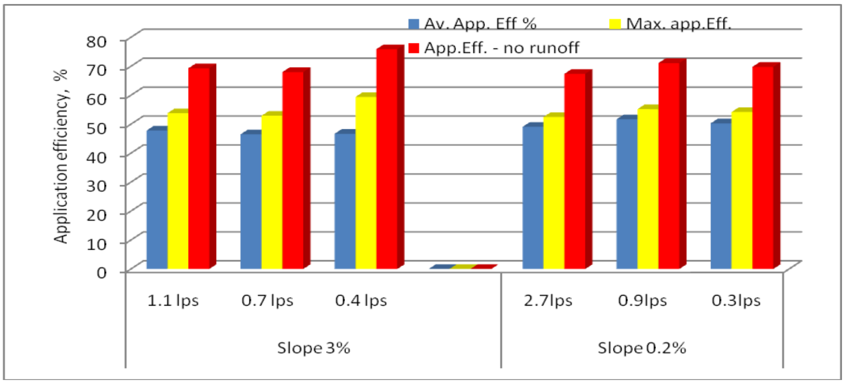

Fig.6 Application efficiency

If the inflow rate is to increase, furrow lengths should be increased in order not to decrease the application efficiency (Fig. 7) but this is limited to 0.2% slope. At higher slope of 3%, as seen in Fig.8, increases in the flow rate beyond 0.7 L/s cause decrease in optimum length for the maximum attainable water application efficiency. When runoff is eliminated or reused maximum attainable efficiency of 75.9% and 71.1% can be achieved with 0.4 L/s and 0.9 L/s in 3% and 0.2% slope respectively. The application efficiency found in this study can be considered low in furrow irrigation, as according to Clemmens and Dedrick (1994) the typical efficiency range is between 60% and 80%. This shows the need of modifying the existing furrow design for improved application efficiency.

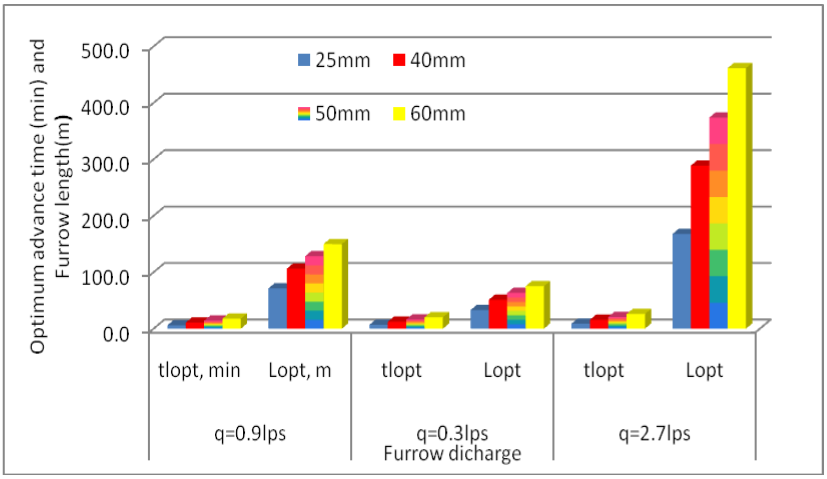

Fig. 7 Optimum advance time and Furrow length under 0.2% slope

Application efficiency is affected by the rate of supply, infiltration rate of soil, storage capacity of the root zone, land levelling, etc. Water is mostly lost through deep percolation at the head end and through runoff at the tail end. Care should be taken to select appropriate flow rate to avoid tail water runoff otherwise runoff reuse should be practiced to improve application efficiency. Application efficiency and uniformity normally increase as the furrow length decreases. On similar soils, and of the same slope and irrigation depth, furrows can be longer when a larger stream size is used for irrigation. This is because water will be advancing rapidly down the furrow. However, the stream size should not exceed the maximum non-erosive stream size determined in field trials. From analysis, it is observed that optimum furrow length increases with water application depth. Optimum furrow length can go up to 400 m with 2.7 L/s in 0.2% slope whereas in 3% slope it is around 100 m with 0.7 L/s. A larger irrigation depth requires more contact time for water to infiltrate to the desired depth than a shallow irrigation depth. The irrigation depth can be increased by making the furrow longer in order to allow more time for the water to reach the end of furrow, which increases the contact time. Care should be taken, however, to avoid too high percolation losses at the top end. Furrows put on steeper slopes can be longer because water moves more rapidly. However, with slopes steeper than 0.5% (0.5 m drop per 100 m length), the stream sizes should normally be reduced to avoid erosion, thus shorter furrows have to be used. Under smallholder conditions the maximum slope of 0.5% should not be exceeded (James, 1988).

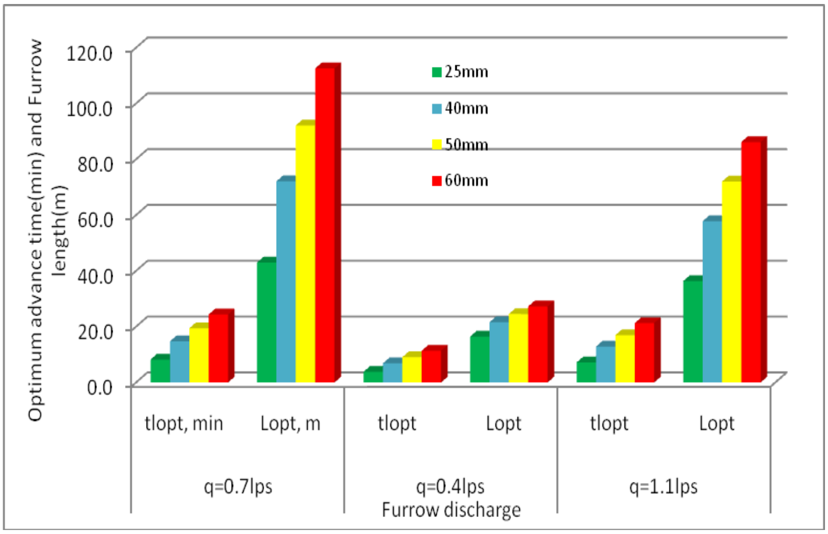

Fig. 8 Optimum advance time and Furrow length under 3% slope

Uniformity of Application

In general it is found that higher uniformity mostly results in low application efficiency and vice versa. In the present experiment also it is proved. Higher uniformities are observed in 0.3 L/s and 0.9 L/s under 0.2% slope and the corresponding application efficiencies are 50 and 44% respectively. This is mainly due to more percolation in the upstream side caused by long opportunity time for infiltration. Flow rate of 2.7 L/s is practically not suitable for 70 m blocked furrow in 0.2% slope due to overflow at the end of the furrow. Flow rate of 0.3 L/s permits more application depth with good uniformity at 70 m furrow length with 0.2% slope but its maximum attainable application efficiency is less than that of 0.4 L/s inflow rate in 3% slope. Flow rate of 1.1 L/s gives maximum uniformity with the limitation of 22 mm average depth of application and less maximum attainable application efficiency compared to other flow rates. But recommendations of inflow rates are made based on both application efficiency and uniformity. Uniformity of water application is governed by furrow slope and flow rate. Furrows should be put on proper gradients that allow water to flow along them and at the same time allow some water to infiltrate into the soil. Furrows put on steeper slopes can be longer because water moves more rapidly resulting poor uniformity of application. However, with slopes steeper than 0.5%, the stream sizes should normally be reduced to avoid erosion, thus shorter furrows have to be used. Under smallholder conditions the maximum slope of 0.5% should not be exceeded (James, 1988). In slope of 0.2% slope, inflow rate of 0.9 L/s will be more ideal in all aspects. Distribution uniformity of 60 to 80% was observed by Lecina *et al*. (2005) when evaluating furrow-irrigated fields in Zaragoza, Spain (85.7% ± 2.2%) and by Hanson *et al*. (1995) in California (81.0% ± 11.3%). The present study results are in good agreement with their findings. In 3% slope both the application efficiency and distribution uniformities were low compared to slope of 0.2% inferring the need to lower inflow rate.

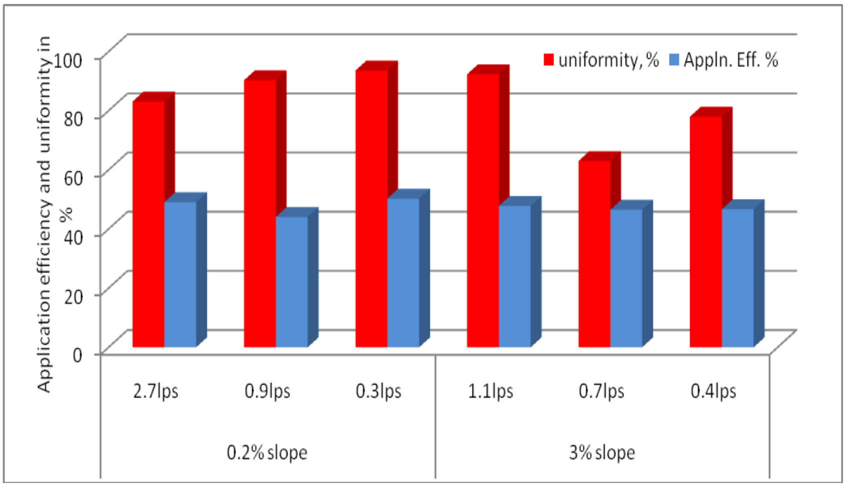

Fig. 9 Uniformity of application under different flow rates

In higher slope increasing the flow rate causes better uniformity but lower application efficiency in 70 m furrow length. In 200m furrow length Arbat (2011) found that when the flow rate was 3.30 L/s, twice that of the current situation, most of the water losses due to deep percolation took place at the end of the furrow. In comparison with the current situation, the distribution uniformity was reduced by up to 84.1% even though the application efficiency barely changed. This infers that higher flow rate in short length furrows improves uniformity of application rather than long furrow length. Analysis of variance indicates that at 0.2% slope 0.3 L/s performed well followed by 0.9 and 2.7 L/s with standard error of 0.45%, critical difference of 1.26% and coefficient of variation of 0.63%. At 3% slope 1.1 L/s performed well followed by 0.4 L/s and then 0.7 L/s with standard error of 0.08%, critical difference of 0.4 and coefficient of variation of 0.14%. It is also observed that during the average soil water content was 12% which will be sufficient for most crops according to Dzingai (2010).

CONCLUSION

Empirical power functions for water front advancement in the furrow and cumulative infiltration depth have been fitted for different inflow rates under existing slopes of the farm where furrow irrigation is practiced for onion cultivation. The fitted power function parameters are used to determine actual and maximum attainable application efficiencies. Time ratio is found as crucial to influence application efficiency under varied flow rates and slopes. Condition for maximum attainable application efficiency is found in terms of optimum time ratio expressed with power parameters of advance and infiltration functions. Actual opportunity time was determined considering recession time of the water front in the furrows and results in significant correction in arriving time ratio and thus the actual application efficiency.

Optimum furrow length can be calculated using the optimum time ratio giving maximum attainable application efficiency.

Higher uniformity of application can be achieved by adopting less flow rate of 0.3 L/s in 0.2 percent slope with average application efficiency of 50.3% and provides scope for higher depth of water application. Increasing the depth of irrigation can improve uniformity of application when 0.3 L/s inflow rate is adopted. Detailed analysis of optimum time ratio under different in flow rates for various irrigation depths reveals that for optimum furrow length and maximum application efficiency, the advance time should be two quarter of the total irrigation in the study area. Flow rate of 2.7 L/s or more should be avoided since it results in poor uniformity and limits irrigation water application depth to just 8mm in the downstream end in addition to soil erosion. Recommended to practice irrigation either three sets of six furrows at a time with furrow inflow rate of 0.3 L/s or single set of 6 furrows at a time with furrow inflow rate of 0.9 L/s which are considered as more optimum flow rates. This will reduce water loss due to runoff and poor uniformity of application as it happens in the current practice of irrigation with pump discharge.

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