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Performance Evaluation of Infield Sprinkler Irrigation System under Existing Condition in Beles Sugar Development Project, Ethiopia

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Abstract

In Beles Sugar Development Project sugar cane fields was faced poor irrigation water management that under watering in most fields, dry spot and over watering in rare fields were observed. Therefore, the main objective of this study was evaluating the performance of infield sprinkler irrigation system under existing condition. The actual water application uniformity was measured for single and four overlapping sprinklers by installing catch can at a grid spacing of 3 × 3 m with two replications at hydrant pressure of 2.5 and 3.0 bars. The performance parameters analyzed were, uniformity coefficient (CU), distribution uniformity (DU), and system uniformity, pressure and discharge variation along laterals also analyzed. The average actual DU and CU obtained at 3 and 2.5 bars at existing sprinkler spacing of 18 m ×18 m was 53% and 63% respectively. The value of CU was lower than the recommended value of 75%. In order to determine alternate sprinkler spacing's under existing working condition, the catch can data for single sprinkler were overlapped for different spacing's whereas respective DU and CU were estimated. For both 2.5 and 3 bar operating pressure; 12 × 18 m, 12 × 12 m, 18 × 12 and 9 × 12 m sprinkler spacing's were in between good and excellent acceptable range. Keeping in view economy, wider spacing, 12 × 12 m is recommended to have excellent water distribution with CU equal to 85% and 87% at operating pressure of 2.5 bar and 3.0 bar respectively. The actual average sprinkler discharge variation along laterals was above and out of the range accepted value up to 10%, whereas the actual average pressure variation along laterals is within the accepted range value of 20% but in some field laterals other than the test area, the variation was above the accepted range value of up to 20%.

Keywords: Uniformity coefficient; Distribution uniformity; System uniformity; Pressure variation; Discharge variation; Sprinkler spacing

Introduction

Effective, sustainable, and efficient sprinkler irrigation system is a combined effect of proper system design, maintenance, operation and management. Therefore, the success of this combined effect improves appropriate field irrigation practices.

Irrigation efficiency is an essential component of any irrigation system management due to its relationship with the water losses and energy and the labor requirements for implementing a sustainable irrigation scheme. According to Osei [1] any sprinkler irrigation system with distribution uniformity (DU) of 85%, in the field, is excellent and acceptable. Oweis and Hachum [2] wrote that the principal indices for evaluating the performance of farm irrigation systems are: uniformity of water distribution, adequacy of irrigation, and efficiency of irrigation. According to Dalton and Raine [3] an important component of the evaluation of in-field irrigation system performance is the assessment of irrigation uniformity. Irrigation uniformity is thus an important management factor necessary for achieving high irrigation efficiency.

Irrigation uniformity is linked to crop yield through the effects of under or over irrigation. Sprinkler irrigation water distribution uniformity is affected significantly by: Equipment and design factors such as sprinkler characteristics (that is number of Nozzles, size and shape), operating pressure and sprinkler spacing; Environmental factors such as humidity and more importantly wind condition; and Management factors such as length of irrigation time, time of day irrigation is Performed, practicing of offsetting laterals (alternate sets) and irrigating blocks of several adjacent laterals at once [4]. Bhuiyan [5] states that: "There is a need for more research work to develop appropriate system evaluation criteria that could be used for systematic but rapid identification of irrigation systems weaknesses and strengths, and also for the better evaluation of management improvement efforts."

Tana Beles Integrated Sugar Development Project is the one among the new sugar development projects in Ethiopia. The major crop to be cultivated is Sugar cane which is estimated to be around 50,000 ha of land [6]. The project has started seed and commercial cane plantation activities in 2012 and covered a total of 11927 hectare using overhead Sprinkler Irrigation System.

The project after the start of cane plantation activity, it faces poor filed irrigation water management, such as non-uniformity of water application. Due to this; under watering in most fields, dry spot and over watering in rare fields were observed. So far there was no study done in this area concerning performance evaluation of infield sprinkler water application. Therefore, the main objective of this study was evaluating the performance of infield sprinkler irrigation system under existing condition.

The specific objectives were:

1. To evaluate the performance of infield sprinkler system water application under existing working condition of the system.

2. To determine alternate sprinkler spacing under existing working condition of the system.

Materials and Methods

Description of the study area

The study was conducted at Tana Beles Integrated Sugar Development Project which is located near Fandica Town, capital

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of Jawi Woreda, which is found in the western periphery of Amhara National Regional State, 149 and 70 km from Bahir Dar and Dangela towns, respectively. The study area has low to medium relief differences with an altitude range of 806 to 1242 meters above sea level.

The project area is located close to Pawe station, can be characterized as warm humid climate with mean annual humidity reaching to 80% and the maximum temperature fluctuating between 37°C in April and 27°C in July, while the minimum temperature variation is bounded between 12°C (December) and 19°C (July). Over all, the project area is considered to be humid with relative humidity ranging between 66 and 92% with more than 50% the year reaching about 80%. The mean annual rainfall around the irrigation scheme is represented by Pawi Station with mean annual rainfall of 1576 mm (from 1986-2006) Feasibility and Design Study of TBISDP [7]. The 44.4% of irrigation command area has a gently slope range from (2-5%). Verti sols cover more than 50% of the command area among the five categories of soil types.

Assessment of the existing sprinkler irrigation practices

Assessment of current sprinkler irrigation practice was done by referring the feasibility and design study document, field observation, field report and by physical contact with Technical responsible Staffs such as Irrigation, and Plantation Staff. The assessment contained: i) irrigation setting hour per day, ii) sprinkler water application uniformity, v) pipe breakage and leakage, hydrant valve and nozzle leakage and breakage, irrigation system service, care and maintenance.

Materials used

The materials used to collect the primary data were four sprinklers, 36 m flexible drag hoses which connect the hydrant and the all the 4 sprinklers , catch cans, graduated cylinder, stopwatch, tape meter, water bucket container, plastic water hose (4 m) used to measure nozzle discharge, hydrant pressure gauge, hammer, sticks for catch can handling, wires and other related accessory materials

Description of catch-cans and installation

Cans of identical measurement were used for the test. The Irrigated Crop Management Centre [8] also recommended at least 30 cans, of minimum height of 100 mm, for the evaluation of sprinkler irrigation uniformity. For this study, 64 catch-cans which are considering the actual sprinkler wetting radius of 13 m were used for the determination of the sprinkler water distribution pattern involving a single sprinkler and 36 catch-cans for the four overlapping sprinklers in practice (block test). The catch - can setup used for this test was adopted square grid that representative of the existing sprinkler operating condition. The test was conducted at TM3 field with two different plots and two hydrant operating pressure which are representative of the existing fields of different elevations. The tests were conducted with the actual average sprinkler discharge of 0.9 and 0.8 m³/h at 3.0 and 2.5 bar hydrant operating pressure respectively. The test plots were selected to see the operating pressure variation due to elevation difference of the field and most of fields were working with these hydrants bar operating pressures. They located at elevation of 1157 and 1160 m downstream and upstream respectively.

For the purpose of evaluating sprinklers, the typical catch-can spacing used should be 2 m or 3 m [9,10]. The catch can spacing (center to center) used for this study was 3 m × 3 m, considering the radius of throw of the sprinklers >12 m and sprinkler spacing >10 m. [1].

To determine the single sprinkler water distribution pattern, the sprinkler was located at the center of a 3 m square grid. The sprinkler was sited equidistant from the four surrounding catch- cans and a continuous grid of 8 columns by 8 rows of catch can collectors were surrounded the sprinkler.

To determine water distribution of the actual overlapping four sprinkler working simultaneously was conducted with two laterals consisting of two sprinklers per each installed in a square configuration of 18 m × 18 m. This spacing was corresponded to 65% overlapping of the sprinkler coverage diameter under light to moderate wind conditions in square or rectangular patterns as recommended by Phocaides [11]. A 3 m square grid of catch- cans made up of 6 rows and 6 columns were installed between four sprinklers. The run time for both single and four sprinklers were 2 hours. The catch volumes were measured with graduated cylinder and recorded, starting with the outermost part of the wetted pattern and ending with the central part, as suggested by Osei [1]. Evaporation loss was measured using four catch can near to the test area for similar catch can running time of 2 hours and recorded an average of 4% loss. The sprinkler heads used for this study were of the full circle rotating impact sprinkler type of Rain bird 14070 h and design capacity of 1.8 m³/h at 3.1 bar working pressure. The catch cans layout and placement for single and block sprinklers (Appendix 1A) (Figures 1 and 2).

Pressure measurement

The actual hydrant valves operating pressure along lateral which deliver water for the sprinklers were measured using hydrant pressure gauge. The recorded pressures were included from the first lateral end up to the last end of hydrant positions. The gauge was held from the hydrant valve to record the operating pressure of the hydrant. The hydrant pressure measurements were taken before the catch cans were overturned to the start of sprinklers discharge record and collection of precipitations. Because of, the absence of pressure gauge with Pitot tube to measure the nozzles operating pressure the following empirical formula was used to determine the nozzle operating pressure:

$$q = ca\sqrt{2gh} \tag{1}$$

q=nozzle discharge m³/s;

a=cross section area;

h=hydraulic head m;

g=acceleration of gravity, 9.81 m/s²;

c=coefficient, it was calculated with equation 4.1 by using the design values of q=1.8 m³/hr; h=3.0 bar and nozzle diameter d=5.0 mm, the obtained value of c was 1.0.

Sprinkler discharge measurement

The actual sprinkler volumetric discharge of the test area was measured with the aid of 4 m flexible plastic water hose connecting with nozzle and collected using plastic water bucket container. To see the actual sprinkler discharge variation across lateral, discharge records were taken with the same aid from the first lateral end to last end of hydrant positions. The time taken to fill the bucket was recorded and the discharge is determined using the Equation:

$$q=v/t \tag{2}$$

Where, q-discharge of sprinkler (l/s);

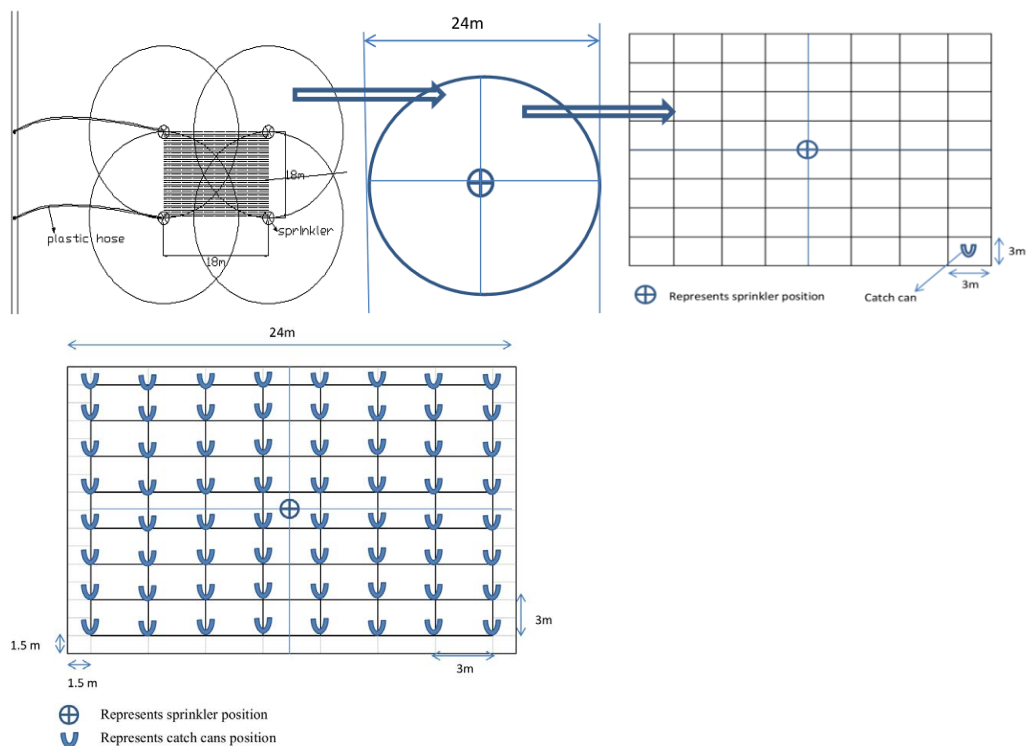v=volume of water collected in liters (l);

t=time taken to fill container (s).

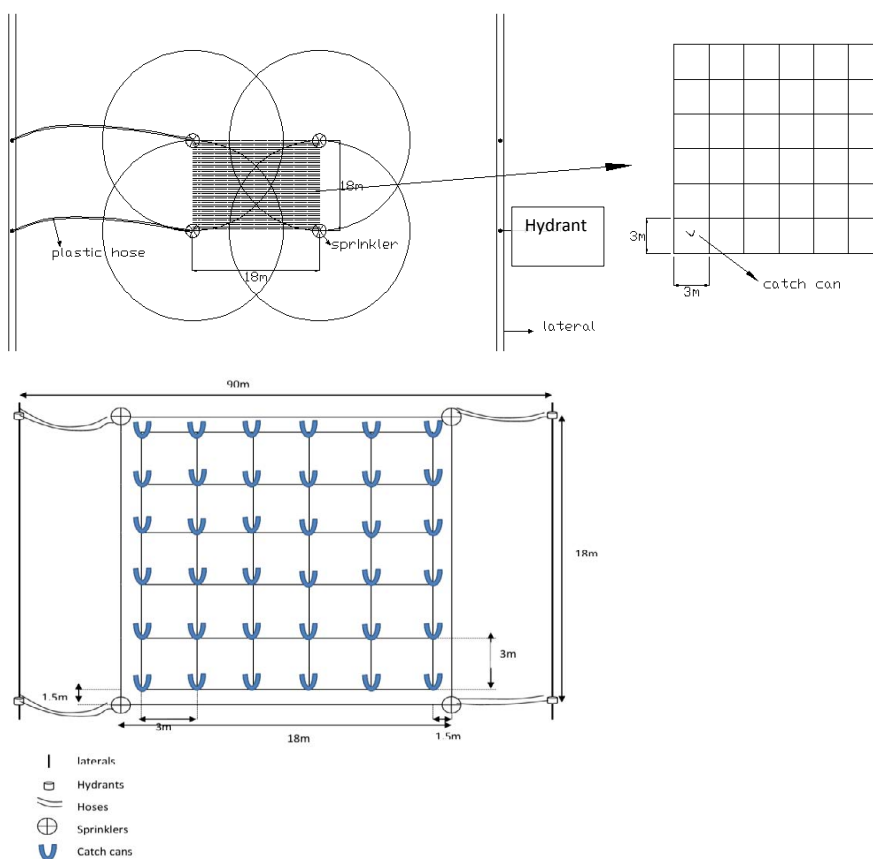**Figure 1:** Catch cans layout and placement for single sprinkler.

Figure 2: Catch can layout for four overlapping sprinklers (Block test).

Performance parameters analysis

The following parameters were estimated to evaluate the performance of infield sprinkler irrigation system under existing condition.

Christiansen's uniformity coefficient (Cu): The coefficient of uniformity for each field was computed by the formula which is proposed by Christiansen [12] stated in eqn. (3). The depth of water in catch can in mm was obtained by dividing the measured volume of water in catch cans by cross sectional area of the catch cans.

$$Cu = \left(1 - \frac{\sum |x_i - \overline{x}|}{n\overline{x}}\right) *100 \qquad (3)$$

Where, x_i =depth of water in catch can;

$\overline{x}$ =mean depth caught in mm;

n=number of sample (catch can).

Distribution uniformity: The distribution uniformity was estimated as the ratio of the average irrigation depth applied to the driest quarter of the plot and the average depth applied across the whole field, which were collected using catch cans. The formula used was following Merriam and Keller [13] as stated in equation 4

$$Du = \frac{xavlq}{xav} \qquad (4)$$

Where, Du is distribution uniformity, xavlq is average irrigation depth applied to the driest quarter of the field, and xav is the average depth applied across the whole field (or grid).

System uniformity: The uniformity is usually a lesser amount when the entire sprinkler system is considered. This is due to greater pressure variation in the system than at any given lateral position [9,10]. The system uniformity of the study area was evaluated using the following formulae.

$$system\ CU \approx CU\left[\frac{1}{2}\left(1 + \sqrt{\frac{pn}{pa}}\right)\right] \qquad (5)$$

$$system\ DU \approx DU\left[\frac{1}{4}\left(1 + 3\sqrt{\frac{pn}{pa}}\right)\right] \qquad (6)$$

Where, pn-minimum sprinkler pressure in the whole field;

pa-the average sprinkler pressure in the entire system over the field area.

The stated pressures were obtained by converting the measured values of sprinklers discharges across lateral using equation 1.

Sprinkler discharge variation along lateral: The Sprinkler discharge variation across lateral of the current irrigation system of the study area was estimated as the ratio deduction of the maximum and minimum sprinkler flow rate to average sprinkler flow rate. The measured discharge data were given in Appendix 1B.

$$= \left(\frac{Maximum - Minimum\ sprinkler\ flow\ rate}{Average\ sprinkler\ flow\ rate}\right)*100\% \qquad (7)$$

Pressure variation along laterals: The Pressure operating variation along laterals of the current irrigation system of the study area was estimated as the ratio deduction of maximum and minimum hydrant valve operating pressure to average hydrant valve operating pressure.

$$= \left(\frac{Maximum - minimum\ hydrant\ valve\ pressure\ along\ lateral}{Average\ hydrant\ valve\ pressure\ along\ lateral}\right)*100\% \qquad (8)$$

Result and Discussion

Assessment of the sprinkler irrigation system design and water application practice

The operation service, care and maintenance of the irrigation systems were clearly put in the Feasibility and Design Study document. But, in practicing, the operation, care and maintenance of the system has its own gap such as: rainy season shut down of gravity off takes as soon as possible to protect the passing of runoff sedimentation or any debris through the system and for ease clear of matters and maintenance of the gravity off takes, regular checkup of gravity off takes for clear of debris, flushing of valves for every 4 to 6 weeks to clear out any deposit of debris, careless handling of valves, immediate irrigation maintenance correction for any system defects, timing assembled information record about system failure (such as: location, timing of failure, failure types, cause of failures), daily system operating pressure checkup. Thus, the effects of all these combined gaps create the system to poor, and malfunction, increasing cost of maintenance, and final reduces the system irrigation efficiency. To ensure the system efficiency, it is better to follow operation, care and maintenance as per the Feasibility and Design Study document guide lines.

The sprinkler irrigation system is designed to nozzle discharge of 1.8 m³/h at a nozzle operating pressure of 3.1 bar and hydrant valve operating pressure of 4.0 bar. But, now most of fields are working below these operating pressures that mean the required discharge is not achieved as per the design. The laterals were designed with actual spacing of 90 m, but in some fields it is more or less than this value. The sprinklers were designed with spacing of 18 × 18 m, but in some observed fields the existing spacing in practice was less or more than this value. Finally these cause non uniformity of water application in most fields and over application of water in some fields.

Performance parameters analysis

The following parameters were analyzed to evaluate the performance of infield sprinkler irrigation system under existing condition of the study area were resulted and discussed below

Actual operating pressure, discharge and wetted radius: The actual measured filed sprinkler system operating pressure, discharge, and wetted radius of the study area were given (Table 1). The operating Pressure and sprinkler discharge variation along lateral was estimated using equations 8 and 7 respectively. The data were given in Appendix 1B

The sprinkler system is designed to work at a hydrant and nozzle pressure of 4.0 and 3.0 bars respectively. The designed sprinkler discharge and wetted radius is 1.8 m³/hr and 15.9 m. According to this study the actual operating pressure, discharge and wetted radius

Field No	Average hydrant pressure (bar)	Nozzle diameter (mm)	Average sprinkler discharge (m³/hr)	Sprinkler application rate (mm/hr)	Average wetted radius (m)	Discharge variation along laterals (%)	Pressure variation along laterals (%)
TM3-22"R1	3.0	3*5.1	0.9	2.8	13.8	12	18
TM3-N11R	2.5	3*5.1	0.8	2.5	11.5	14	20

Table 1: The actual operating pressure, discharge, and wetted radius of the study area.

is working under the design operating condition. The actual average sprinkler discharge variation along laterals is above and out of the range accepted value up to 10%, whereas the actual average pressure variation along laterals is within the accepted range value of 20% [9,10] but in some other field laterals other than the test area, the variation is above the accepted range value of up to 20%. Generally the cause of the under operating capacity of the study area irrigation system, the sprinkler discharge and pressure variation along laterals are the combined effect of insufficient flow capacity from the gravity intake due to the filling of off take filter with unnecessary large debris and dust, pipe breakage and leakage due to passage of dust through the pipe system, the field elevation difference, the hydrant valve and gravity plastic hose move breakage and leakage, nozzle clogging and leakage. The filter situated only at the gravity off take is meshed filter, due to this any soil particle or sedimentation and large debris were easily passed to the pipe system and as well as the existing filter was not cleared at appropriate time. Having these, the sprinkler irrigation system installed was working blow the required efficiency.

Sprinkler application uniformity: The actual sprinkler application uniformity of the four 65% overlapped sprinklers which are positioned at 18 m spacing are evaluated and given (Table 2).

According to this uniformity result table the average actual DU and CU at 3.0 and 2.5 hydrant bar pressure are 58% and 48%, 67% and 59% respectively. As shown in the Table 2 the application uniformity is varying in morning and afternoon at the same hydrant pressure and sprinkler discharge due to the wind and evaporation effect. According to DU>65% and CU>78% is considered as the minimum acceptable performance level for economic system design [9,10]. For general field and forage crops DU is >60% and CU>75%. According to this study the actual sprinkler application uniformity at 3.0 hydrant bar pressure is near to the starting range of acceptable value but it is out of the acceptable range whereas at 2.5 hydrant bar pressure it is very far from the start range of acceptable value. For both hydrants operating pressure the actual application uniformities were out of the acceptable range. This showed that the actual acceptable sprinkler application

uniformity is achieved when the system is worked at a hydrant pressure of greater than 3 bars. Accordingly the system is designed to work with a full capacity at a hydrant pressure of 4.0 bars, but currently the system is working with a hydrant pressure of 3.0 bar and below. Thus, in order to achieve the acceptable application uniformity the system has to be functional with the full design capacity. As shown in the table the system application uniformity is less than the test area application uniformity (DU and CU); the system uniformity is usually less when the entire sprinkler system is considered, due to greater pressure variation as whole than a lateral position [9,10].

Sprinkler precipitation profile: According to the field measurement test taken, the actual application uniformity of a single sprinkler which was work alone was very differ from time to time at the same hydrant pressure and sprinkler discharge due to wind and evaporation effect. The actual average distribution uniformity at 3.0 and 2.5 bars is 36% and 30% respectively, whereas the actual average CU at 3.0 and 2.5 bars is 58.5% and 51.5% respectively. The actual application uniformity of the 65% overlapping sprinklers is greater than the single sprinkler working alone. This shows that the acceptable actual application uniformity is achieved when sprinklers are overlapped together to reduce the wind effect.

The actual single sprinkler precipitation profile for sprinkler discharge 0.83 and 0.94 m³/hr at hydrant operating pressure of 2.5 and 3.0 bars (Figure 3).

As shown in Figure 1, both of profiles depicted a sprinkler operating at too low pressure. Under such conditions, the water from the nozzle concentrates in a ring a distance away from the sprinkler resulting in a poor precipitation profile [14]. According to this study the system operating pressure at 2.5 and 3.0 was categorized under low operating pressure.

Distribution and coefficient of uniformity overlapped with different spacing: Sprinkler uniformity is affected by spacing between sprinklers [9,10]. Thus, in order to see the spacing effect of sprinkler application uniformity and to suggest the spacing which gives the

Field No	Hydrant pressure (bar)	Coefficient of uniformity (CU, %)		Distribution Uniformity (DU, %)		System CU (%)		System DU (%)	
		Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
TM3-22"R1	3.0	62	71	55	61	59	67	50	55
TM3-N11R	2.5	59	59	49	46	55	55	44	41

Table 2: The actual application uniformity of the overlapping sprinklers of the study area.
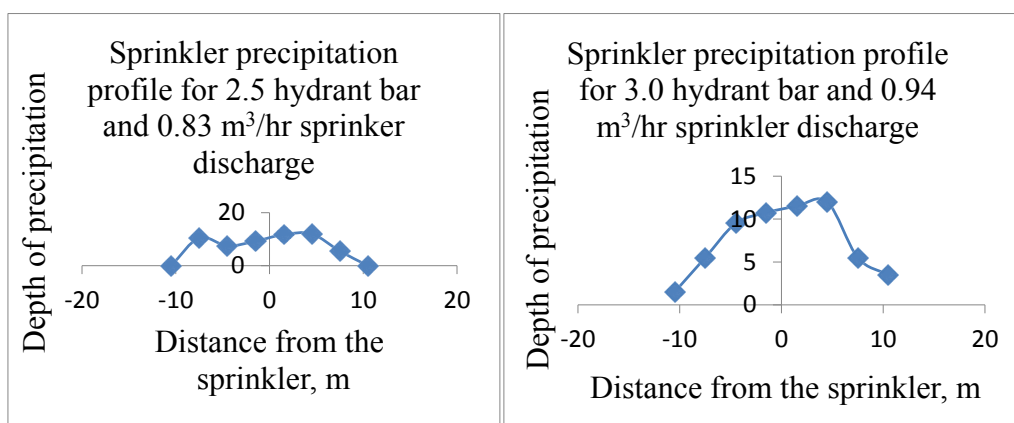

Figure 3: The actual single sprinkler precipitation profile at 2.5 and 3.0 hydrant bar.

acceptable uniformity value, the actual measured single sprinkler catch can depth data was overlapped with different spacing of 12 × 18 m, 12 × 12 m, 18 × 12, and 9 × 12 m. The data was overlapped accordingly with spacing's and with their respective hydrant bar operating pressure using spreadsheet program which was similar as suggested by Merkley and Allen and Phocaides [9,10]. The overlapped catch can data for the single sprinkler of the stated spacing's were given in Appendices 1C, 1D, 2. The application uniformity of these different spacing's were shown in Table 3.

Spacing	DU and CU value of different overlapping spacing of a single sprinkler			
	At 2.5 bar hydrant pressure		At 3.0 bar hydrant pressure	
	DU (%)	CU (%)	DU (%)	CU (%)
12 × 18 m	67	75	73	76
12 × 12 m	79	85	80	87
18 × 12 m	70	73	64	78
9 × 12 m	85	87	87	88

Table 3: Distribution and Coefficient of uniformity of a single sprinkler overlapped with different spacing.

As shown in Table 3, DU and CU value of the stated sprinkler spacing's for both of hydrant operating pressure was in acceptable range of DU >60 and CU > 75% [9,10]. But, the DU and CU value of the actual overlapping sprinkler spacing of 18 × 18 m as stated in Table 13 above was not in acceptable range. Therefore, 12 × 18 m, 12 × 12 m, 18 × 12 and 9 × 12 m spacing were suggested for achieving acceptable uniformity value for both of stated hydrant bar operating pressure. Specially 12 × 12 and 9 × 12 spacing had very good and excellent acceptable range respectively. Keeping in view economy, wider spacing, 12 × 12 m is recommended to have excellent water distribution with CU equal to 85% and 87% at operating pressure of 2.5 bar and 3.0 bar respectively.

Conclusions and Recommendations

The evaluation of Beles sprinkler irrigation systems has great importance. The system performance and sustainability is under question that any large debris can pass easily through the trunk main up to the sprinkler nozzle. The operation, care and maintenance of the system are not satisfactory. There is no common fixed cleaning week for the whole system. Particularly the existing meshed filter at the gravity off take is cleaned and maintained when it is closed with debris and the system capacity is becoming low. As a result, system pipe clog, breakage and leakage are regular actions. Therefore, to keep and sustain the system performance; it is better to follow operation, care and maintenance of the whole system from the gravity off take up to the sprinkler nozzle as per the Feasibility and Design Study document guideline.

According to the study the determined average sprinkler discharge and wetted radius at a hydrant operating pressure of 3.0 and 2.5 bars were 0.9 and 0.8 m³/hr, 13.8 and 11.5 m respectively. These shows that the system is working under design capacity of 4.0 hydrant bars with sprinkler discharge and wetted radius of 1.8 m³/hr and 15.9 m, respectively. Thus, the system has to be improved and revised in order to attain the full design capacity. Sprinkler discharge variation across laterals were 12 and 14% at a hydrant pressure of 3.0 and 2.5 bar respectively. This shows that the discharge variations along laterals are

out of the acceptable range of 10%. Thus, Care has to be taken for the system leakage, breakage and nozzle clogging and breakage.

The actual average pressure variation along laterals is within the accepted range value of up to 20%. But, in some other field laterals the variation is above the accepted range value of 20%. Thus, the project has to give attention for the system leakage, breakage, hydrant valve clogging with debris and the lateral elevation difference which cause pressure variation along lateral.

The average actual DU, and CU of 18 m overlapping sprinklers at 3.0 and 2.5 hydrant bar pressure were 58% and 48%, 67% and 59% respectively. These values were not in acceptable range. Therefore, in order to attain the acceptable water application uniformity the system has to be work either with full design capacity or the system sprinkler spacing has to be improved if it is working with 3.0 and 2.5 bars. The DU value for a single sprinkler overlapped with 12 × 18, 12 ×12, 18 × 12 and 9 × 12 m spacing at 2.5 bar hydrant operating pressure was 67, 79, 70 and 85% respectively and CU value of 75, 85, 73 and 87% respectively. The DU value for a single sprinkler overlapped with 12 × 18, 12 × 12, 18 × 12 and 9 × 12 m spacing at 3.0 bar hydrant operating pressure was 73, 80, 64 and 87% respectively and CU value of 76, 87, 78 and 88% respectively. These all values are in acceptable range and the values show that, the application uniformity of sprinklers is increasing with decreasing of sprinklers spacing. Keeping in economy, the spacing which gives the optimum value is very important.

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