EVALUATING THE ADEQUACY PERFORMANCES OF SPRINKLER IRRIGATION SYSTEM AT FINCHAA SUGARCANE PLANTATION, EASTERN WOLLEGA ZONE (ETHIOPIA)[†]

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ABSTRACT

The success of sprinkler irrigation system largely depends on its actual performance at field condition. Although the uniformity of water application is the most important aspects in the sprinkler systems performance, adequacy better explains the performance of the system. In this study, the adequacy of irrigation performance was measured actually at field condition considering three operating hydrant pressures (4.0, 4.5 and 5.0 bars) and two sprinkler nozzle sizes (2.4 * 4.4 and 2.4 * 4.8 mm). The main objective of this study was to determine the level of current adequacy of irrigation performance in relation to the predicted performance during the design period. Three different adequacy performances (delivery, infiltration and storage) were determined from the measurements of the two important basic sprinkler performance parameters: discharge and uniformity. The study result indicates excess irrigation water application more than the crop net irrigation requirement and soil moisture deficit, especially for the 2.4 * 4.8 mm nozzles sprinkler at all pressure ranges considered. Inline to this, tremendous losses in terms of deep percolation (≅ 40%) have been observed, the consequence of which is leaching of soluble nutrients, loss of valuable water resources, reduced crop yield and rise of groundwater table. The later one might lead to drainage problems, which requires construction of expensive drainage

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[†] L'évaluation de la performance d'adéquation des Système d'irrigation par aspersion dans la plantation de canne à sucre de Finchaa, (Zone Est de Wollega, Ethiopie)

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system and can also lead to the overall waterlogging, salinization and alkalization of the area.

KEY WORDS: adequacy; performance indices; percolation losses; sprinkler nozzles; uniformity.

RÉSUMÉ

Le succès du système d'irrigation par aspersion dépend en grande partie de ses performances réelles au champ. Bien que l'uniformité de l'application de l'eau soit l’aspect le plus important de la performance d’un système aspersif, l'adéquation explique mieux la performance du système. Dans cette étude, l'adéquation des performances de l'irrigation a été mesurée au champ sous trois pressions de fonctionnement (4.0, 4.5 et 5.0 bars) et deux tailles de buses d'arrosage (2.4 * 4.4 et 2.4 * 4.8 mm). L'objectif principal de cette étude était de déterminer le niveau de l'adéquation actuelle de la performance de l'irrigation par rapport à celle prévue par conception. Trois performances d'adéquation différentes (livraison, infiltration et stockage) ont été déterminées à partir des mesures des deux paramètres de base importants de la performance d'arrosage : le débit et l'uniformité. Le résultat de l'étude indique une application d'eau d'irrigation excédentaire résultant du besoin net en eau de la culture et de l'humidité nette du sol net pour les deux buses et toutes les gammes de pression considérées. Des pertes énormes en termes de percolation profonde (40 %) ont donc été observées, avec pour conséquence le lessivage des éléments nutritifs solubles, la perte de précieuses ressources en eau, la réduction du rendement des cultures et l'élévation de la nappe phréatique. Ceci pourrait conduire à des problèmes de drainage, ce qui nécessiterait la construction d'un système de drainage coûteux ou pourrait également conduire à l'engorgement général, la salinisation et l'alcalinisation de la région.

MOTS CLÉS : adéquation ; indices de performance ; pertes par percolation ; buses d'arrosage ; uniformité.

INTRODUCTION

In any irrigated agriculture including sprinkler irrigation systems, an adequate and dependable water supply is needed in order to facilitate irrigation water application in accordance with the biological and physiological needs of plants. That means irrigation water supply should fully satisfy the irrigation water requirements and irrigation frequency during the irrigation water supply (Dinka, 2004). This requires an understanding of the interactions between the soil, water, plant and climate. Unless the adequate and timely supply of irrigation water is assured, the physiological activities taking place within the plants are adversely affected, which results in reduced yield of crops (Patil et al., 2012). The ability of the irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the production system (Raine and Foley, 2002; Griffiths 2006). Uniform water distribution is necessary for maximizing crop yield and quality as well as for more efficient use of the available irrigation water (Ascough and Kiker, 2002).

Although the uniformity of water application is the most important aspects in the sprinkler systems performance (Solomon, 1979; Maroufpoor et al., 2010), adequacy better explains the performance of the system (Chaudry, 1976; Dinka, 2004). It is generally agreed that a Christiansen's uniformity coefficient (CU) value of 0.80 is 'adequate' or 'acceptable' for sprinkler irrigation, this value is difficult to interpret in a physical sense since it does not indicate whether the fields are adequately irrigated or not (Dinka, 2004). The uniformity level does not give any physical meaning about the adequacy of irrigation water application. The adequacy of irrigation performance indicates the ability of an irrigation system to deliver the required amount of water that can be stored in the effective root zone and meet the Crop Water Requirement (CWR). An adequate irrigation is defined as one which replenishes the root zone over 95% of the irrigated area. This means that the depth of water effectively used in meeting CWR can be taken as the depth that is equalled or exceeded over 95% of the area (Cuenca, 1989). Though an adequacy level can be above 100%, the economics of irrigation usually dictates an adequacy level below 100% (Allison and Hesse, 1969).

Finchaa Sugar Estate (FSE), established in the 1990s in Finchaa Valley of Ethiopia, uses dragline sprinkler irrigation system. The sugar estate is the first large scale irrigation scheme to use sprinkler irrigation in the Ethiopian history. The recommended irrigation cycle and sprinkler set-time during the design were 15 days and 24 hours, respectively (Dinka, 2004), for all soil types and plant conditions, even though the two soil types (i.e. Chromic Luvisols and Eutrophic Vertisols) prevailing in Finchaa Valley have completely different water holding capacity. Furthermore, the recommended sprinklers are brass impact type (Ura-Riego VYR 35 or Ura-Costa Re) with two nozzles (2.4 * 4.8 mm diameter) designed to give a gross discharge of 5.6 mm/hr (0.5 l/s) at 4.5 bar hydrant pressure (i.e., 3.17 bar sprinkler pressure) (Tate and Lyie, 1982). The sprinklers are spaced at 18m x 18 m distance along and across the laterals.

However, during the preliminary field survey, a deviation from the recommended design condition was observed in both operating pressure and sprinkler-nozzle combinations. The sugar estate is also irrigating using the sprinkler nozzles (2.4 * 4.8 mm) that do not conform to the design specification at an operating pressure different from the design value. Every sprinkler with nozzles has its own hydraulic and hydrodynamic performance. In addition, the sprinkler nozzles have a problem of wear and tear through time which may increase diameter of the sprinkler nozzles and the associated problems such as the change in drop size condition of a sprinkler spray, increased precipitation rate from sprinkler nozzles, change in uniformity of water application or distribution, etc (Dinka, 2004). Such changes might result in negative externalities such as waterlogging, salinization and ultimately reduced crop yield.

Critical evaluation of the sprinkler irrigation system is very important in order to identify whether the system is operating at the required performance level and then suggest improvements to the operation of the system. Irrigation performance assessment is an essential component of the general performance of the sugar estate. Moreover, in-field performance evaluation indicates both the location and magnitude of water loses that are occurring, and then determining how to improve the irrigation system and/or its operation (Al-Ghobari, 2006). It also assists the system management or decision makers in determining whether performance is satisfactory and, if not, which corrective actions need to be taken in order to improve the situation (Julaia, 2009).

The serious water management problem at FSE may be due to incorrect design and/ or poor operation of sprinkler irrigation system. It is necessary to quantify the design and management performance of the sprinkler system at FSE. The bottleneck in irrigation water management of the sugar estate has got special attention by irrigation professionals in recent times. All attempts made so far to alleviate the water management problems of FSE were based on the normal hydraulic design condition. The soil, crop and climatic factors were more or less evaluated in those studies (Teferi, 1995; Dinka, 2004). But, no critical research based on the recommended standard procedures has been conducted regarding the actual performance of sprinkler irrigation system at FSE. Without the knowledge and information of the actual field performance of the sprinkler irrigation system, all attempts made to alleviate the water management problems of the estate remains incomplete and fruitless.

The current study presents the results of field performance investigation of dragline sprinkler irrigation system in use at FSE. The level of current adequacy performances of the irrigation system in relation to the targeted/expected adequacy level during design period has been evaluated. Six different combinations of operating pressures and sprinkler nozzle sizes were evaluated and an optimum combination that can adequately perform under the prevailing field condition were selected and recommended. The underlying hypothesis of the study are: (i) the adequacy of irrigation better explains the performance of sprinkler irrigation compared to uniformity; (2) the adequacy performance for the two soil types (Luvisols and Vertisols) is expected to be different; (3) the adequacy performance of the two sprinkler types is expected to be different; and (4) the design operating pressure (4.5 bar) and sprinkler nozzle size (2.4 * 4.4 mm) combination might not be the best performing ones as far as adequacy of water application is concerned.

MATERIALS AND METHODS

Brief description of the study area

This study was conducted at Finchaa Irrigation Scheme, which is located in Western Oromiya Regional State at a distance of about 340 km from the capital city (Figure 1). It is situated within 9°30' to 10°00 ' North and 37°30' East with an average altitude of 1350 – 1600 m+MSL (metres above mean sea level). The valley is surrounded by almost parallel, near vertical escarpments which rise approximately 700 to 850 m above the valley floor on the East, West and South directions. The valley floor in the project area is genteelly undulating with a general slope of 1 to 8% extending from South to North. Finchaa River is the tributary of Abay River (main tributary of Blue Nile). It divides FSE in to Western and Eastern banks.

The Long Years (1979-2012) Average (LYA) mean annual rainfall was about 1315 mm, which is high enough for rainfed cane agriculture. But, about 77% of the stated rain amounts fall within four months (June to September) consecutively. The other eight months (Oct to May) are termed as 'dry season' and, hence requires supplemental irrigation. Sometimes, there is an appreciable amount of rain falling in the month of October and May and also an occasional heavy rainfall during the month of April.

The LYA mean maximum and minimum monthly temperature in the Finchaa Valley are 31.5 °C and 14.6 °C, respectively, with the mean value of about 23.6 °C, which is favourable for sugarcane crop. Maximum temperature occurs in March and the minimum in December. The mean daily wind speed is about 3.5 km/hr at 2m heights, which is low and desirable for sprinkler irrigation system. Generally, Finchaa Valley can be characterized by a moist sub-humid with large winter water deficiency and megathermic temperature efficiency regime (Adinew, 2001).

Two major groups of soils are available in Finchaa Valley: Reddish Brown (Chromic, Hepallic and Gleyic) Luvisols and the Black Clay Eutric Vertisols, which accounts about 73% and 27% of the sugar estate, respectively. Most of these soil types were developed from alluvial and culluvial deposits of the surrounding escarpment (Teferi, 1995; Dinka, 2004).

Data collection and analysis

In order to check whether the sprinkler irrigation system at FSE is adequate or not, the field irrigation performance has been evaluated. The study mostly concentrated on the aspects of adequacy performances. Three levels of sprinkler adequacy performance measures (adequacy of water delivery, adequacy of water infiltration and adequacy of water storage) were determined from the measurements of the two basic sprinkler performance parameters: discharge and uniformity. The performance parameters were measured at six combinations of operating hydrant pressure and sprinkler nozzle sizes (i.e., 4.0, 4.5 and 5.0 bars operating hydrant pressures and 2.4 * 4.4 mm and 2.4 * 4.8 mm diameter nozzle sizes). The hydrant pressures considered for the tests are within the recommended pressure variation (± 20%) from the mean (design) value (4.5 bar). Now onwards, the term 'pressure' is used instead of 'hydrant pressure' throughout this document.

(a) Discharge measurement

The discharge rate from individual sprinkler was measured on two fields (G0266 and PS316) having a lateral length of 540 m and 340 m, respectively. The selected fields are harvested fields just at the inception of irrigation for the next ratooning (cane cycle), which makes the measurement easier. Also, the selected fields are representative for most of the estates fields and lateral conditions. The discharge was measured across the lateral at selected three (first, middle and end) riser positions with two replicates by connecting a flexible hose or tube to the range (larger with 4.4 and 4.8 mm diameter) and spreader (smaller with 2.2 mm diameter) nozzles, and allowing the water to fill a known volume of barrel (208 lit) for a measured period of time.

The discharge from individual sprinkler was calculated using Equation 1. Then, the application rate (R_a) (Equations 2) was computed from the measured discharge and sprinkler spacing.

$$Disch\arg e = \frac{Volume\ of\ \ water\ \ collected\,(Lit)}{Test\ \ period\ (Sec)} \quad (1) \quad Ra = \frac{3600q}{s_l * s_m} \qquad (2)$$

where, R_a = application rate (mm/hr), q = sprinkler discharge (l/s), S_l = sprinkler spacing across the lateral (m), and S_m = sprinkler spacing on the main line (m). In the case of Finchaa Sugar Estate, S_m = S_l = 18 m. And hence, Equation 2 will be simplified as:

$$R_a = 11.11q \quad for\, Finchaa\, case \qquad (3)$$

(b) Uniformity measurements

The performance of sprinkler irrigation system is normally evaluated based on uniformity coefficients determined from field measurements using an array of water collecting devices (Topak *et al.,* 2005). In the current study, the uniformity of water application of sprinkler irrigation was measured using catch-cans on sugarcane plantation fields considering the two major soil types (i.e., Eutric Vertisol and Chromic Luvisol) prevailing at Finchaa Valley. The catch-cans have an opening diameter of 7.7 cm and 20 cm height placed on plastic pegs of height 22.4 cm.

Uniformity measurement was conducted by using single sprinkler and four sprinklers methods. The uniformity measurements were done on selected four cane plantation fields (G0-266, PS-370, and G0-115 and PS-316). The field layouts for uniformity test using single and four sprinkler methods are illustrated in Figure 2. For the uniformity measurement using four sprinkler methods, 36 plastic pegs were installed between the squares bound by four sprinklers in a square grid patterns of 3 m * 3 m intervals (Figure 2b). In the case of uniformity measurements using single sprinkler (Figure 2a), 108 plastic pegs were installed around the centrally located sprinkler with 3m square grid pattern. Then, soil samples were collected at selected peg positions for the determination of the initial (pre-irrigation) volumetric water content. The sprinkler is then allowed to simulate water through sprinkler nozzles continuously for a period of about 22 hours, which is the set time of irrigation at FSE. During the continuous water application, surface uniformity was measured (with three replicates) by positioning graduated plastic catch-cans a top of each peg for a period of 2 hours in average. Finally, the final (post-irrigation) volumetric moisture content was determined by collecting the soil samples just after the sprinkler shut-off and then certain times after the sprinkler shut-off time (i.e., 12 hrs for Luvisols and 24 hrs for vertisols).

In the case of uniformity measurement using single sprinkler, the performance of the sprinkler according to the overlap pattern by four sprinklers in the actual field operation was evaluated, approximately, by superimposing the individual observations one upon the other and summing together from different positions based on the geometric similarities and wind effects.

The soil samplings were done by probing the soil using the soil auger up to the depth of 60 cm with 30 cm increment. The samples were collected using the moisture can for the moisture content determination on mass basis and using core for the bulk density determination. The soil depth of 60 cm was considered due to the fact that the effective root depth of sugarcane at FSE is 60 cm.

The coefficient of uniformity (CU) was evaluated using the Christiansen (1942) formula (Equation 4).

$$CU = 100\left[1 - \frac{\sum X}{n * m}\right] \tag{4}$$

where, X = |z-m| = absolute deviation from catch observations (mm), m = mean observation, n = number of observations

Finally, the application ratio and the three adequacies of irrigation performances (adequacy of water delivery, adequacy of water infiltration and adequacy of water storage) were determined based on the methods proposed by Chaudry (1976) and adopted by Dinka (2004) and Bishaw (2012), by comparing the actual field performance (measured value) to the expected performance (set during the design). The level of adequacy of water delivery (A_d) was estimated based on the values of mean water application/delivery ratio (R_d) and its deviation from unity. The A_d value (Equation 5) is defined as the ratio of the average depth of water actually obtained flow rate (R_a) from sprinkler nozzles to that of the expected or predicted gross application rate during the design (i.e. 5.6 mm/hr). The adequacy of water infiltration (A_i) (Equation 6) is defined as the ratio of the mean depth of water observed in the catch cans to the desired net depth of application set during design (4.2 mm/hr by considering an application efficiency of 75%. The adequacy of water storage (As) (Equation 7) is defined as the ratio of the depth of water actually stored in the effective root zone to the net depth of irrigation water expected (4.2 mm/hr) at the 75% application efficiency.

$$A_d = \frac{average\ \ flowrate\ \ from\ \ sprinklernozzles}{Gross\ application\ rate} * 100 \tag{5}$$

$$A_i = \frac{average\ catch\ depth}{Net\ depth\ of\ \ irrigatin\ desired} * 100 \tag{6}$$

$$A_s = \frac{average\ water\ \ storage\ in\ effective\ root\ \ zone}{Net\ depth\ of\ \ irrigatin\ \exp\exp ected} * 100 \tag{7}$$

RESULTS AND DISCUSSIONS

Adequacy of water delivery performance

The adequacy performance of water delivered by sprinkler was evaluated based on the values of the mean water application/delivery ratio (R_d) and its deviation from unity (Figure 3). The R_d value is the ratio of the average depth of water actually obtained flow rate (R_a) from sprinkler nozzles to that of the expected or predicted gross application rate during the design (i.e.

5.6 mm/hr). Those areas receiving the depth of irrigation greater than or equal to the expected application depth are considered to be adequately irrigated.

The obtained R_d values are in the ranges of 0.9 - 1.0 for the 2.4 * 4.4 mm nozzles sprinkler, and from 1.13 - 1.34 for the 2.4 * 4.8 mm nozzles sprinkler at the considered respective pressures. The R_d values are less than unity for 2.4 * 4.4 mm nozzle sprinklers and greater than unity for the 2.4 * 4.8 mm nozzles. From Figure 3, it is possible to envisage the relationship between water delivery ratio compared with the operating pressure and nozzle sizes. The R_d value is strongly (direct) correlated with both operating pressure and nozzle size. That means the water delivery performance increased as operating pressure and nozzle size increased, which is in agreement with other similar studies elsewhere (Ahaneku, 2010; Bishaw, 2012).

Here, it is most important to note that the highest R_d value do not indicate the better adequacy of water delivery performance. The better adequacy performance level is indicated based on the deviation of R_d from unity (Figure 3). The more the deviation of R_a from unity approaches zero, the better the water delivery performance will be. The increase in operating pressure resulted in an increased deviation of R_d from unity for the 2.4 * 4.8 mm nozzle, while the opposite is true for the 2.4 * 4.4 mm nozzles (Figure 3). In other words, the adequacy of water delivery is increasing and approaching zero as operating pressure increases for the 2.4 * 4.4 mm nozzles; whereas the adequacy of water delivery decreases as operating pressure increases for the 2.4 * 4.8 mm nozzles.

Adequacy of water infiltration/application performance

The distribution pattern and obtained adequacy of irrigation performance is presented in Figure 4 for the different combinations of operating pressure and sprinkler nozzle sizes. The A_i value was determined based on the assumption that the mean depth of water observed in the catch cans is infiltrated into the soil profile and then compared with the desired net depth of application set during design (4.2 mm/hr by considering an application efficiency of 75%). In this case, adequacy represents the percentage of the field receiving the desired amount of water or more.

For the 2.4 * 4.4 mm nozzle sprinkler, the obtainable A_i values are 6, 81 and 86%, at the respective hydrant pressures of 4.0, 4.5 and 5.0 bars (Table I, Figure 4). For this sprinkler nozzle, the adequacy levels are below 100% at all the pressures considered. This means that there is certain level of water stress associate with this sprinkler type. The 6% adequacy at 4 bar pressure indicates that more than 90% of the field receives an application depth of water less than the desired net irrigation requirement. This shows the highest degree of crop stress due to under irrigation when the 2.4 * 4.4 mm nozzle sprinkler operates at 4.0 bar pressure. However, the adequacy level increases to 47% considering lower application efficiency, for-example 70% (see

Figure 5). For the 65% application efficiency, the adequacy level becomes about 90%, which is acceptable value. Further reduction of the application efficiency to 60% will result in an increase in the adequacy of irrigation to 100%. But, it should be noted that application efficiency less than 70% is not economical for solid set sprinkler irrigation systems (Cuenca, 1989; Keller and Bliessen, 1990).

The reduced adequacy of water application in the case of 2.4 * 4.4 sprinklers may be attributed to the following (environmental) factors: i) reduced drop size, which may be easily carried away by winds; ii) lower operating pressure than recommended value; iii) the wear and tear of the sprinkler nozzles. The consequent of the above factors is ultimately the reduction in application efficiency and an increase of lost/wasted water.

At the extreme condition, the 2.4 * 4.8 mm nozzle sprinkler operating at 5.0 bar pressure has the adequacy level of 134%, which indicates the excess water application more than the crop net irrigation requirement. That means energy is being wasted since the cost of irrigation water application increases with the increment of operating pressure. For the same nozzle sprinkler (2.4 * 4.8 mm), the 4.0 and 4.5 bar pressures have acceptable level of adequacy greater than 80%. The 4.5 bar pressure has better adequacy of water application compared to that of the 4.0 bar pressure.

It can be visualized from Figure 4 that the 2.4 * 4.8 mm nozzle has higher adequacy of water application value than the 2.4 * 4.4 mm nozzle at each and every operating hydrant pressures considered. This may be due to the greater discharge and higher drop size of sprinkler spray from the larger nozzle. For the 2.4 * 4.8 mm nozzle sprinkler, the depth of water application is greater than the required depth at all pressures considered. However, the greater adequacy level does not indicate the better adequacy performance as discussed in the preceding session. Furthermore, the adequacy of irrigation increases as the operating hydrant pressure increases for both the sprinkler nozzle combinations. In general, adequacy of irrigation water infiltration increase as the operating pressure and sprinkler nozzle diameter increases. The relationship between the coefficient of uniformity and adequacy of water application can be visualized from Figure 6. The higher adequacy performance is associated with the lower uniformity performance, except for 2.4 * 4.8 mm nozzles at 4.5 bars, at the five combinations of operating pressure and nozzle sizes.

Adequacy of water storage performance

The sub-surface moisture distribution and adequacy of water storage is presented in Figure 7 for the two soil types and two sprinkler nozzle combinations. The adequacy of water storage performance presented in Figure 7 was determined from the measurements of sub-surface uniformity test. Actually, it was determined from the mean storage rate (R_s), which is the ratio of the depth of water actually stored in the effective root zone to the net depth of irrigation water expected (4.2 mm/hr) at the 75% application efficiency.

It is evident from Figure 7 that the 2.4 * 4.8 mm nozzle has higher adequacy of water storage value than the 2.4 * 4.4 mm nozzle at each and every operating pressures considered. This is actually expected since there was excess water application in the case of the 2.4 * 4.8 mm nozzle sprinkler type. The result is in line with the adequacy performances of water delivery and application. For the 2.4 * 4.4 mm nozzle sprinkler, the depth of water storage is greater than the required storage depth at 4.5 and 5.0 bar pressures. For this sprinkler type, a good water distribution was obtained at 4.0 bar pressure only. For the 2.4 * 4.8 mm nozzle, on the other hand, the depth of water storage is greater than the required depth at all pressures considered. The excess water application more than the required depth is an indicative of excess water application and deep percolation loss in the area.

Deep percolation loss and relative yield reduction

The net depth of application (I_{ad}), relative production (Y_a/Y_p) and deep percolation loss (L_d) are summarized in Table I. The I_{ad} and L_d values were determined from the values of distribution coefficient (H) and Storage Coefficient (E) presented in Cuenca (1992) at the different Coefficients of Uniformity (CU) and adequacy (A_i) levels determined during the surface uniformity test. Furthermore, the relative production (Ya/Yp) at the obtained adequacy and uniformity coefficient level was estimated from Keller and Bliesn (1990) by assuming that over-irrigation do not bring yield reduction. This is based the assumption that areas receiving the depth of irrigation greater than or equal to the expected application depth are considered to be adequately irrigated and there is no yield reduction since the CWR is fully satisfied.

The L_d obtained varies from 4 - 16% and 13 - 40%, respectively for the 2.4 * 4.4 mm and 2.4 * 4.8 mm sprinkler nozzles. The L_d determined reflects the increased deep percolation loss as the direct function of adequacy level. There is a significant increase in deep percolation loss as the percentage of area receiving adequate irrigation increased (Table I or Figure 6). The effect of adequacy level on the deep percolation loss is greater than that of the uniformity. The deep percolation of about 40% was obtained when the 2.4 * 4.8 mm nozzle operates at 4.5 and 5.0 bar pressures. This high L_d value is uneconomical and intolerable in sprinkler irrigation system.

It is interesting to observe from the Table I that the higher application depths do not indicate the higher net application depth infiltrated and stored in the effective root depth. The obtained net application depth increased as the adequacy of water application (up to 100%) and uniformity increased; whereas net application depth decreased as uniformity decreased and adequacy increased. Another interesting idea obtained from Table I is that higher uniformity (80%) is not an indicator of the better adequacy of irrigation.

General discussion

Table III presents the summary of the three adequacy levels at different pressure and nozzle size combinations. The status of adequacy levels in Table III was made based on the classification and associated problems shown in Table II. The detailed description of each adequacy ranges are provided in Table II. The result obtained (Table III) clearly indicates that higher adequacy performance of water delivery is not a guarantee for the higher level of water application/infiltration and storage performances at lower operating pressures. This argument is better explained by the value of A_d (90%) compared to A_i (6%) and A_s (33%) for the 2.4 * 4.4 nozzles sprinkler operating at 4.0 bar pressure. This is probably due to the lower drop size from sprinkler spray from lower nozzles operating at lower pressure, which can be easily carried away by winds. For the relatively higher nozzle sizes (2.4 * 4.8 mm), a high level of A_d is an indication of higher values of A_i and A_s at all pressures considered, with the exception of Luvisols at 4.0 bar pressure. Furthermore, for the same sprinkler, a higher A_d is an indication of higher values of A_i and A_s at all pressures considered.

The acceptable adequacy range provided in Tables II and III was made based on the assumption that -20% and +10% deviation of adequacy from 100% is acceptable. But an adequate irrigation is defined as the one which replenishes the root zone over 95% of the irrigated area. Accordingly, for the 2.4 * 4.4 mm nozzle, none of the considered pressure and nozzle combinations are adequate for Luvisols. For the same soil type, 2.4 * 4.8 mm nozzles operating at 4.5 and 5.5 pressures are adequate. Similarly for the case of 2.4 * 4.8mm nozzle, all the considered combinations of nozzle size and operating pressure are found to be adequate, except for the 2.4 * 4.4 mm nozzle sprinkler operating at 4.0 bar pressure. However, the economics of irrigation usually dictates an adequacy level less than 100%. Therefore, if adequacy level between 95 - 100% is the desirable value, then none of the considered operating pressure and sprinkler nozzles combinations is found to be within the desirable range for both soil types.

In the case of Luvisols, the A_s value is below 100% for the 2.4 * 4.4 mm nozzle sprinkler at all pressures considered. For the same soil type, the A_s value is greater than 100% for the 2.4 * 4.8 mm nozzle sprinkler, except at 4.0 bar pressure. The A_s level is greater than 100% for Vertisols at all combinations of operating pressure and nozzle sizes, except for the 2.4 * 4.4 nozzle at 4.0 bar pressure. That means excess amount of water is stored in the root zone, which results in excess water loss in the form of deep percolation and groundwater recharge.

In general, the result clearly indicated that excess amount of water is delivered from the 2.4 * 4.8 mm nozzles at the three considered pressures. The author suggests the possibility of using lower operating hydrant pressures (3.0 or 3.5 bar) in areas operated by this type of sprinkler nozzle. Based on the obtained level of adequacy of water delivery and infiltration performances, it is possible to suggest that 5.0 bar operating pressure is the best operating pressure for the 2.4 * 4.4 mm nozzles; whereas 4.0 bar pressure is the best for the 2.4 * 4.8 mm nozzle sizes. At the design operating pressure (4.5 bars), there is over irrigation for the 2.4 * 4.8 mm nozzles sprinkler and slightly under irrigation for the 2.4 * 4.4 mm nozzle. The water delivery performance at the design operating pressure and nozzle size is found to be satisfactory and acceptable. Considering the adequacy of water storage performance, the best combination of operating performance in the case of Luvisols was obtained when the 2.4 * 4.4 mm nozzle operates at 5.0 bar pressure and 2.4 * 4.8 mm nozzle operating at 4.0 bar pressure. For Vertisols, none of the considered combinations of operating pressure and nozzle sizes are found to be adequate. Relatively, the 2.4 * 4.4 mm nozzle sprinkler operating at 4.0 bar pressure can be considered as adequate since there might be a contribution from groundwater through capillary rise.

Considering the three adequacy performances (Table III), the best combinations of nozzle sizes and operating pressure are the 2.4 * 4.4 mm nozzle operating at 5.0 bar pressure for Luvisols. That means, the design operating pressure (4.5 bar) and sprinkler nozzle size (2.4 * 4.4 mm) combination is not the best performing ones as far as adequacy of water application is concerned. There is no best operating pressure for the 2.4 * 4.8 mm nozzle. However, the same sprinkler operating at 4.0 bar pressure is relatively adequate. That is why the author suggests the possibility of using lower operating hydrant pressures (3.0 or 3.5 bar) in areas operated by the 2.4 * 4.8 mm nozzle sprinklers. However, the final selection of a particular combination of operating pressure and sprinkler nozzle size is mostly dictated by the economics of water exploitation considering the allowable crop water stress, water/energy saving, and the associated yield reduction.

It should be noted that the status of adequacy level designated as 'adequate' for the adequacy levels in the ranges of 80 - 90% (Tables III) depends on the magnitude of groundwater table below the crop root zone (since shallow water tables contribute to crop root zone through capillary rise) and the magnitude of allowable crop water stress and yield reduction compared to the water/energy savings. Thus, the final decision for the recommendation of optimum combination of operating pressure and sprinkler nozzle size should be done based on the optimization of crop production considering the deficit and/or surplus irrigation and the associated problems. In the study area, the groundwater table is rising to the surface in some fields and hence the practice of deficit irrigation is highly recommended.

CONCLUSION AND/OR RECOMMENDATION

This study result clearly indicates the importance of adequacy performance compared to uniformity performance for sprinkler irrigation system at Finchaa Sugarcane plantation. The obtained uniformity performance level is greater than the minimum acceptable value (80%) for sprinkler irrigation at the six combinations of operating hydrant pressures and sprinkler-nozzle sizes. However, the uniformity level does not give any physical meaning about the adequacy of irrigation water application. The three adequacy performances determined in this study confirm the stated argument.

The higher adequacy values in the case of 2.4 * 4.8 mm nozzles sprinkler indicate the excess water delivery beyond the need of crops irrigation requirement and the soil moisture deficit. This leads to increased deep percolation loss, leaching of soluble plant nutrients, low water application efficiency (i.e. loss of valuable water resources), reduced in quality and quantity of crops, and also a rise of water table. The later one might lead to drainage problems, which requires construction of expensive drainage system and can also lead to the overall salinization and alkalization of the area. The situation is specifically dangerous for Eutric Vertisols having the highest capillary rise. High values of deep percolation loss (40%) and yield reduction (13%) was observed, which is uneconomical and intolerable in sprinkler irrigation system. There is a significant increase in deep percolation as the percentage of area receiving adequate irrigation increased. The effect of adequacy level on the irrigation water performance and yield reduction is greater than that of uniformity. It is possible to conclude that a good uniformity performance level may not be an indicator of the good adequate irrigation performance level.

The economics of irrigation system usually dictates less than 100% of the area to be adequately irrigated, but the acceptable value should be greater than or equal to 90%. Therefore, based on the recommended adequacy level, the 2.4 * 4.4 mm nozzle sizes of sprinkler has by far better and acceptable adequacy of irrigation performance than that of the 2.4 * 4.8 mm nozzle sizes sprinkler at all operating pressures considered. For the 2.4 * 4.4 mm nozzles, the adequacy performance level is good and acceptable at all operating hydrant pressures; whereas it is poor and unacceptable for the 2.4 * 4.8 mm nozzles, except at 4.0 bar operating pressure.

Based on the findings of this study, the following recommendations are suggested by the author:

- the best combination of operating pressure and sprinkler nozzle sizes are the 4.5 bar pressure for 2.4 * 4.4 mm nozzles sprinkler. That means, the design operating pressure (4.5 bar) and sprinkler nozzle size (2.4 * 4.4 mm) combination is not the best performing ones as far as adequacy of water application is concerned. There is no best operating pressure for the 2.4 * 4.8 mm nozzles sprinkler. Generally, the 2.4 * 4.4 mm sprinkler-nozzle combination has better performance than the 2.4 * 4.8 mm sprinkler nozzles. Therefore, the estate is highly encouraged to purchase 2.4 * 4.4 mm nozzle sizes for future use. Moreover, the author suggests the possibility of using lower operating hydrant pressures (3.0 or 3.5 bar) in areas operated by the 2.4 * 4.8 mm nozzle sprinklers by considering the economics of water exploitation. Thus, the estate should try to avoid the combined use of the two sprinkler nozzle types in the same field;

- the 2.4 * 4.8 mm nozzle discharge has been increased tremendously from the expected one probably due to the wear and tear of sprinkler nozzles and poor maintenance of sprinklers. Thus, periodic maintenance of the sprinklers and periodic replacement of sprinkler nozzles, if possible, is suggested. Immediate replacement of the 4.8 mm nozzle diameter is highly recommended;
- the sugar estate should use the best combination of operating pressure, sprinkler nozzle sizes, set time and soil type. A compromise should be made for the adoption of the stated combinations considering the economics of irrigation and field practicability. The final decision for the recommendation of optimum combination of operating pressure and sprinkler nozzle size should be done based on the optimization of crop production considering the deficit and/or surplus irrigation and the associated problems.

Finally, the author would like to recommend the practice of deficit irrigation in the study area since groundwater table is rising to the crop root zone and significant groundwater contribution is expected. Deficit irrigation can be practiced by considering the magnitude of allowable crop water stress and yield reduction compared to the water/energy savings. This requires an optimization study on sugarcane crop production in order to decide the allowable ranges of crop stress for the different combinations of operating pressure and sprinkler nozzle sizes. Moreover, further critical revision of the dragline sprinkler irrigation systems is extremely important to understand the interactions between the wind condition (speed and direction) and the distribution pattern of sprinkler spray.

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REFERENCES

Adinew A. 2001. Summary of Meteorological Data (1979-2000): E.S.I.S.C.SH/CO, RTS Division. Finchaa Research Station. Research report, unpublished.

Ahaneku IE. 2010. Performance evaluation of portable sprinkler irrigation system in Llorin, Nigeria. *Indian Journal of Science and Technology* **3(7)**: 853–857.

Al-Ghobari M. 2006. Effect of maintenance on the performance of sprinkler irrigation systems and irrigation water conservation. *Food Sci. and Agric. Res. Center, King Saud Univ. Res. Bult.*, **141**: 5–19.

Allison SV, Hesse VL. 1969. Simulation of Wind Effects on Sprinkler Performance. Journal of the Irrigation and Drainage Division, ASCE, 95 (4), Proc. Pape (6978).

Ascough GW, Kiker GA. 2002. The effect of irrigation uniformity on irrigation water requirements. *Water SA*, **28(2)**: 235-242.

Bishaw D. 2012. Evaluating the performance of sprinkler irrigation at Wonji-Shoa Sugar Estate. An MSc Thesis submitted to Haramaya University, Ethiopia.

BookerTate. 1994. Irrigation Operations and Maintenance Manual. Finchaa Sugar Project. BookerTate Ltd. Finchaa, Ethiopia.

Chaudry FH. 1976. Non-Uniform Sprinkler Irrigation Application Efficiency. *Journal of the Irrigation and Drainage Division* ASCE 104 (IR2). Proc. Paper 1302.

Christiansen JE. 1942. Irrigation by Sprinkling. California Agriculture Experiment Station Bulletin No. 670.

Cuenca RH. 1989. Irrigation System Design: An Engineering Approach. Prentice Hall, Englwood Cliffs, New Jersy, USA

Dinka MO. 2004. Evaluating the field water application performance of sprinkler irrigation system at Finchaa Sugar Estate. MSc Thesis submitted to ArbaMinch University, Ethiopia.

Griffiths, B. 2006. In-field evaluation of irrigation system performance. Thesis submitted to University of KwaZulu-Natal for MscEng Degree. Pp36.

Julaia, C. de S. 2009. Performance assessment of water distribution in large scale irrigation: Case study of Chokwe Irrigation System in Mozambique. Thesis (MSc). Delft, The Netherlands: UNESCO-IHE.

Keller J, Bliesn RD. 1990. Sprinkler and Trickle Irrigation. Van Nestrand Reinhold. New York.

Maroufpoor E, Faryabi A, Ghamarnia H, Moshrefi GY. 2010. Evaluation of Uniformity

Coefficients for Sprinkler Irrigation Systems under Different Field Conditions in Kurdistan Province (Northwest of Iran). *Soil & Water Res.* ***5*****(4)**: 139–145.

Patil P, Kulkarni U, Desai BL, Benagi VI, Naragund VB. 2012. Fuzzy logic based irrigation control system using wireless sensor network for precision agriculture. Proceedings AIPA 2012, India.

Raine, SR and Foley, JP. 1999. Performance of in-field application systems. In: ed. Raine, SR, Research, Development and Extension in Irrigation and Water Use Efficiency: A Review for the Rural Water Use Efficiency Initiative, ch. 4, 22-45. National Centre for Engineering in Agriculture, University of Queensland, Toowoomba, Australia.

Raine SR, Foley JP. 2002. Comparing application systems for cotton irrigation - What are the pros and cons. Field to Fashion. 11th Australian Cotton Conference. Australian Cotton Growers Research Association, Brisbane, Australia.

Rao PS. 1993. Review of selected literature on indicators of irrigation performances. IWMI, Colombo, Srilanka, 75p.

Solomon KH. 1979. Variability of sprinkler coefficient of uniformity test results. *Transactions of the ASAE* **22**: 1078–1086.

Tate and Lyie technical report. 1982. Finchaa Sugar Project Studies (Phase 2 Vol.2). Tate and Lyie Technical Services Ltd. England.

Teferi G. 1995. Finchaa Sugar Project Soil Survey and Land Management Units Final Report (West Bank) Main Report (Vol. 1.) submitted to finchaa Sugar Factory, unpublished.

Topak R, Suheri S, Ciftci N, Acar B. 2005. Performance evaluation of sprinkler irrigation in a semi-arid area. *Pakistan J. Biological Sciences* **8** (**1**): 97–103.

Walker WR. 1978. Explicit Irrigation Uniformity: Efficiency Model. *Journal of the Irrigation and Drainage Division* ASCE l05 (IR2). Proc. Paper 14608.

Table I. Estimated values of deep percolation loss (L_d), Net application Depth (I_{ad}) and Relative Production (Ya/Yp)

Nozzle size (mm)	P (bars)	CU (%)	A_i (%)	Ž (mm/hr)	H (-)	E (-)	I_{ad} (mm/hr)	L_d (%)	Y_a/Y_p (%)
2.4 * 4.4	4.0	95.6	6	3.89	1.000	0.960	3.89	4	87
	4.5	89.6	81	4.66	0.894	0.880	4.17	12	98
	5.0	89.0	86	4.78	0.853	0.842	4.08	16	98
2.4 * 4.8	4.0	90.3	83	4.67	0.886	0.873	4.14	13	98
	4.5	87.7	98	5.62	0.620	0.610	3.48	39	100
	5.0	89.9	134	5.63	0.600	0.600	3.38	40	100

Ž - mean catch depth

CU - coefficient of uniformity

H - distribution coefficient

E - Storage coefficient

A_i – Adequacy of water application

I_{ad} - Net applied depth

L_d - Deep percolation loss

Y_a - actual yield

Y_p - Potential yield

Y_a/Y_p - relative yield

Table II. Classification of adequacy levels and the associated problems for sprinkler irrigation

Adequacy range (%)	Status	Water Supply	Status	Description or associated problems
< 60	Extremely poor	Deficit	Inadequate	Highest degree of crop water stress due to extreme water deficit (under irrigation) resulting in very high yield reduction and total crop failure
60-78	V. poor	Deficit	Inadequate	Crop water stress resulting in yield reduction
80 - 90	Good	Deficit	Adequate*	Certain magnitude of moisture deficit and yield reduction is expected
90 – 100	V. Good	Slightly deficit	Adequate	Slight yield reduction
100 – 110	Good	Slightly excess	Adequate*	Slightly excess energy and moisture excess, leading to waterlogging, yield reduction and excess cost of production
110 – 130	V. poor	Excess	Inadequate	Excess energy and moisture excess, leading to waterlogging, yield reduction and high cost of production
>130	Extr. poor	Excess	Inadequate	Extreme excess energy and water supply, resulting in waterlogging, yield reduction, total crop failure and high cost of production

* the status of adequacy level designated as 'adequate' depends on the magnitude of groundwater table and the allowable crop water stress and yield reduction compared to the water/energy savings.

Table III. Summary of the three adequacy levels and the status at different operating pressure and nozzle size combinations

Adequacy Level (%)	Pressure (Bars)	A_d (%)	Status	A_i (%)	Status	A_s (L) (%)	Status	A_s (V) (%)	Status
2.4 * 4.4	4.0	90	Good	6	V. poor	33	V. Poor	75	Poor
	4.5	95	Good	81	Poor	44	V. Poor	119	V. poor
	5.0	100	Excellent	100	Excellent	90	Good	138	Extr. poor
2.4 * 4.8	4.0	113	Poor	111	Poor	75	Poor	140	Extr. poor
	4.5	122	V. poor	134	V. poor	115	V. poor	142	Extr. poor
	5.0	134	Extr. poor	134	Extr. poor	116	V. poor	152	Extr. poor

A_d – Adequacy of water delivery, A_i – Adequacy of water infiltration, A_s – Adequacy of water storage, L – Luvisols, V – Vertisols

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