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A Review on Factors Affecting the Uniformity of Sprinkler Irrigation

Etefa Tilahun Ashine*, Minda Tadesse Bedane

Irrigation and Water Harvesting Research Programme, Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, Jimma, Ethiopia

Email address:

etefatilahun@gmail.com (Etefa Tilahun Ashine), mindat9@gmail.com (Minda Tadesse Bedane)

*Corresponding author

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Abstract: Taking measures to improve water management is of particular importance because the on-going demand for irrigation water may lead to an increase in pressure on water sources. The need to increase irrigation's flexibility and efficiency has led to the development of more advanced pressurized irrigation such as sprinkler irrigation. Sprinkler irrigation is the process of applying water in the form of a spray or in the form of rainfall. Both distribution uniformity and coefficient of uniformity result in approximately the same values when uniformity is high. During applying irrigation water for crops in sprinkler irrigation water mostly lost by wind speed in the form of evaporation. It is affected by the direction and magnitude of the prevailing wind. The other factor that affects the uniformity of irrigation is the raiser height, mainly in windy areas. As the riser height decreases, water application uniformity will increase and also evaporation and drift losses will increase. For wind speeds under 4 m. p. h., they either have minimal or no impact on the distribution pattern. The distribution of irrigation water is also impacted by wind direction relative to lateral lines. When the wind is blowing from the lateral at an angle of between 15 and 45 degrees, a better pattern can be produced. The distribution of water in sprinkler system equipment is influenced by water pressure at the riser as well. Because the slope of the line is less and the higher pressures are better, this suggests that as wind speeds rise, the influence of pressure becomes more pronounced. It is advised that a sprinkler head be used within the manufacturer's specified range of pressures in order to achieve irrigation consistency.

Keywords: Coefficient of Uniformity, Distribution Uniformity, Sprinkler Irrigation, Wind Speed

1. Introduction

Though achieving food security is a goal that should be pursued regardless of the socioeconomic situation in which a country finds itself [1], it is of the utmost importance in developing nations where population growth is coupled with an increase in the frequency and severity of environmental events like floods, droughts, insufficient rainfall that frequently threaten food security [2]. The availability and accessibility of food for impoverished households may also be significantly impacted by higher food costs and income inequalities as a result of increased food demand and decreased crop output. Around 13 percent of the population in developing countries is undernourished, and feeding the world's population is a challenge that is likely to get worse in the future [3]. The number of population is expected to rise to 9.2 billion by 2050 [4], with an anticipated increase in food demand of 59 to 102 percent [5, 6]. In light of the aforementioned, it appears required to boost agricultural productivity between 60% and 70% in order to feed the entire world's population by 2050 [4].

The agricultural sector is essential for boosting food availability and achieving food security [7-10]. Even while it is widely agreed that the need for food will increase internationally in the next decades [11], there is debate as to whether global agriculture will be able to meet this need by increasing the food supply. By increasing agricultural output and expanding the diversity of agricultural land uses, it may be possible to better ensure the availability of food [12, 13]. It highlights the requirement of increasing investments in agricultural research and extension programs for both developed and developing countries in order to boost the productivity of agricultural product per unit of land and per agricultural worker. Initiatives that would increase agricultural productivity without significantly damaging the environment must obviously be given attention. Irrigation is one of the methods to promote technology transfer from industrialized to developing countries, which will support these procedures, decrease technological gaps, and remove knowledge obstacles [14].

The creation of irrigation plans is necessary in regions with insufficient rainfall and significant environmental constraints if there is any chance of increasing agricultural output. By removing water from a source that is already existing, adding water to fields that previously lacked it or had little of it, and establishing artificial buildings and features to extract, move, and dispose of water, irrigation signifies a change in the landscape's natural characteristics [15]. However, for delivering the water from its source, it needs a gravitational (surface irrigation) or pumping (pressurized) irrigation method.

A large group of irrigation techniques that use a free-surface, gravity flow to disperse water over the field are referred to as surface irrigation. Overland flow introduces a flow at a high point or along a high border of the field and permits it to cover the field. Streams and rivers have historically been the most straightforward water sources to exploit because they simply needed a basic river dike and canal to supply water to nearby regions. These low-lying soils often contained a lot of clay and silt and had modest slopes. They are typically more impacted by water logging and salinity issues because many are located on lower land with tighter soils [16]. This technique is used for 95 percent of all irrigation worldwide, making it the most popular. The use of surface irrigation is appropriate for both small and large projects. Surface irrigation techniques include furrow, border, and basin irrigation. The decision between them is based on the crop, farming methods, terrain, soils, and farmer's preferences. Methods of surface irrigation are frequently chosen because they are seen to be straightforward and suitable for farmers with little or no irrigation experience. It was claimed that surface furrow irrigation offers a way to manage and direct water on steep, undulating, and very level ground [17].

In recent years, as irrigation systems have developed, modern sprinkler irrigation methods have taken the place of antiquated surface watering systems. The need to increase irrigation's flexibility and efficiency has led to this development. Although surface irrigation systems are usually considered to be more successful than sprinkler irrigation, it was found that both ET (Evapotranspiration) and SEL (Spray evaporation Loss) may rise with an increase in wind speed, demanding more irrigation water [18]. Taking measures to improve water conservation is of particular importance because the on-going demand for irrigation water may lead to an increase in pressure on both surface and ground water sources. Further, climate change predictions suggest that in the future there will be warmer, windier, and drier conditions, with an increased frequency of drought and storms [19]. As these changes occur, the demand for water resources is also likely to increase. Therefore, increased efficiency in water use and general farming practices will be necessary to maintain and increase agricultural production.

The most significant effects that may result if irrigation efficiency is increased [20] are that a larger area can be irrigated with the same volume of water; the competition between water users can be reduced; energy used for pumping can be reduced; and in-stream flows, after withdrawals, will be larger, thereby benefiting aquatic life, recreation, and water quality. Accordingly, this paper was initiated with the objective to review factors that affect the uniformity of sprinkler irrigation for further design and application of the sprinkler irrigation.

2. Over View of Sprinkler Irrigation

Sprinkler irrigation is the process of applying water in the form of a spray produced by the flow of water pressure via tiny orifices called nozzles, in the form of rainfall. When a stream of water is released from a sprinkler nozzle into the air at a high rate of speed, similar to how rainfall occur, friction between the air and the stream causes the stream to break up into water droplets that fall to the ground [21]. Water can be lost from sprinkler irrigation in three different ways: through the air, from the canopy, and from the ground [22]. Most topographic circumstances make it feasible; the only restrictions are those related to land use capacity and economics [23-25]. Although gravity can also be employed if the water source is situated far enough above the area that needs to be watered, pumping is frequently used to produce pressure.

Careful selection of nozzle diameters, operating pressure, riser height, and sprinkler spacing in sprinkler irrigation can be used to apply the ideal amount of irrigation water needed to refill the crop root zone that can neither cause runoff nor harm the crop and also provide the best uniformity possible under the prevailing wind and management conditions [26-27]. Costs, required uniformity of watering, and the effects of operating pressure and drop size all need to be carefully considered when choosing the precise combination of sprinkler nozzles, operating pressure, and spacing that can compromise the basic determining factors (i.e., soils, climate, and crops) [3, 27].

Commonly, higher water distribution uniformity and irrigation efficiency values indicate best performance; hence uniform application of irrigation water is the main goal of sprinkler irrigation design [26]. Specially, at the current due to a water resources deficit, uniformity and efficiency become important tools for the modern day irrigation performance evaluation [12, 15]. Water losses or application uniformity can both be used to describe in-field water application performance. Although system design and management practices have an impact on both components, the losses are mostly a management issue while the uniformity is primarily a system design issue [4]. Sprinkler irrigation uniformity is a crucial element and a significant indicator of sprinkler irrigation performance [3, 5]. The reduced homogeneity coefficient of a sprinkler irrigation system causes reductions in application efficiency, water productivity, crop yield, and height [7- 9, 14, 28]. Generally, sprinkler irrigation, has the following advantage [29-31],

1) Elimination of the channels for conveyance, therefore there is no conveyance loss.
2) Suitable to all types of soil except heavy clay soil.
3) Suitable for irrigating crops where the plant population per unit area is very high.
4) It is most suitable for oil seeds and other cereal and vegetable crops.
5) It has the highest water saving capability.
6) Closer control of water application convenient for giving light and frequent application.
7) It has the highest irrigation and water application efficiency.
8) Increase in yield.
9) Mobility of system.
10) It is possible for undulating area.
11) Saves agricultural lands.
12) Influences greater conducive micro-climate.
13) Areas located at a higher elevation than the source can be irrigated.
14) Possibility of using soluble fertilizers and chemicals.
15) Less problem of clogging of sprinkler nozzles due to sediment laden water.

Even though it has the above stated advantages, its uniformity is affected as discussed in the following section below.

3. Factors Affecting Uniformity of Sprinkler Irrigation

A sprinkler irrigation system uses pressure energy to form and distribute rain like droplets over the land surface. Although, they are normally designed to supply the irrigation requirements of the farm, sprinkler systems are also used for crop and soil cooling, frost protection, controlling wind erosion, providing water for germinating seeds, application of agricultural chemicals, and land application of waste water. Not only the application of the right amount of water to the field, but also its uniform distribution over the field is important [56]. Permissible lengths of irrigation runs are controlled to a large extent by the uniformity of water distribution which is possible for a given soil and irrigation management practice. Water distribution uniformity indicates the extent to which water is uniformly distributed along the run.

Acceptable values of uniformity coefficient vary with the type of crop being grown and the specific uniformity equation used. Both distribution uniformity (DU) and coefficient of uniformity (CU) result in approximately the same values when uniformity is high. However, DU values are normally much lower than CU values when uniformities are low. For high cash value crops, especially shallow rooted crops, the uniformities should be high (DU values greater than 80% or CU values greater than 87%). For fields crops (DU values should be greater than 70% and CU values greater than 81%). For deep rooted orchard and forage crops, uniformities may be fairly low if chemicals are not injected (DU values above 55% and CU values above 72%). Uniformity coefficient should be high (DU values greater than 80% or CU values greater than 87%) whenever fertilizers or other chemicals are injected into the irrigation systems. If uniformity coefficients are lower than these values, system repair, adjustment or modification may be required. If uniformity coefficients are periodically measured (at least annually), system repairs/ adjustments can be scheduled when coefficients fall below the above values [32].

During applying irrigation water for crops in sprinkler irrigation water mostly lost by wind speed in the form of evaporation. For quantify the magnitude of the evaporation and drift losses during water application by sprinkler irrigation, many studies such as field tests, laboratory, analytic and physical and mathematical, have been conducted. However, the results obtained were different for each study. The losses vary from 2 to 40 % from tests conducted at field [33-35]. Analytic and laboratory investigations losses ranged from 0.5 to 2% [34]. From laboratory tests the droplet evaporation losses in sprinkler irrigation are usually less than 2-3%, even under high air temperature and low relative humidity [36]. Under normal condition they were almost negligible. In comparison, under moderate evaporative condition the losses should not be more than 5-10% [37]. Droplet evaporation during sprinkler irrigation is not only a direct loss of water, but it also has a significant effect on microclimate. It improves the microclimate of the irrigated area by reducing temperature and vapor pressure deficit which leads to a decrease in the transpiration and soil evaporation [38].

Evaluation of irrigation uniformity under field conditions is the most recommended option to analyse the performance of an irrigation system [39]. For the in-field tests conducted under wind speed equal to 3.49 and 4.66m/s, the average collected irrigation depth was greater than that regulated in the laboratory per centimetre (9mm). This allows inferring that the equipment was moving with velocity other than that regulated in its control panel. Additionally, this fact can be attributed to a possible slide of the equipment [40]. Yet, these authors point out that wind has great influence on irrigation uniformity such that the greater the wind speed, the less the uniformity coefficients.

The performance of sprinkler irrigation systems is greatly affected by both the direction and magnitude of the prevailing wind. It is the chief modifier that reduces the diameter of throw and changes the profiles of sprinklers. Wind speed and vapour pressure deficit are the predominant factors that affect evaporation losses significantly during sprinkler irrigation and the losses are correlated with wind speed and vapour pressure deficit [41]. Wind speed in combination with sprinkler spacing has significant impact on the uniformity of set move sprinkler irrigation systems. The problem is observed especially when wind speed exceeds 8 km/h. Another phenomenon associated with the wind condition is wind skips, which occurs when there is a large difference in wind speed and/or direction between adjacent irrigation sets. This creates temporary dry zones adjacent to the sprinkler laterals on the upwind side. It is, however, not cumulative and successive irrigations/moves correct this effect [42].

Wind speed and direction often had little impact on CU and DU values. The uniformity coefficients (CU and DU) do, however, decrease as wind speed increases [43]. During the in-field tests, wind direction was seen to vary in respect to the lateral line of the equipment [44]. For similar wind speeds, the wind direction did not differ in any significant way.

Even though wind is a major contributor to water loss, it can help increase uniformity because the randomness of wind drafts and turbulence contributes to smoothing out the distribution pattern and profile [45]. There are three basic sprinkler spacing pattern types: square, rectangular, and triangular. These designs can also be modified to fit certain circumstances. The square pattern, which can be used to irrigate square-shaped regions, has identical distances running between each of the four sprinkler sites. The diagonal distance between sprinklers in the corners, which is frequently subject to wind impacts, is the constraint of this pattern. To minimize wind effects, closer spacing is recommended, depending on the severity of the wind. The rectangular sprinkler spacing has sprinkler positions forming a rectangle with the shorter side of the rectangle across the wind and the longer side against the wind, so as to obtain good coverage. This pattern has the advantage of fighting windy situations, and it is suitable for areas with defined straight boundaries and corners. In the triangular pattern, sprinklers are arranged in equilateral triangle formats so that the distance from each other is equal. This pattern allows for lengthy spacing and therefore requires fewer sprinklers compared to the square spacing for a specified area. For a wind speed of over 5 m/s, it is possible to adapt a sprinkler spacing of 9, 12, and 10 m for irrigating a diameter of wetted circle of 32, 37, and 42 m [46], as cited by [23].

The other factor which affects the uniformity of sprinkler irrigation is raiser height, mainly in windy areas. Sprinklers that are placed closer to the soil have lower wind drift and evaporation losses, but they may have a smaller wetted radius, which would mean shallower flooding and less uniform water distribution [47, 48]. According to [49], as the riser height decreases, water application uniformity will increase. Evaporation and drift losses range from 5.2% for a riser height of 1.0 m and an operating pressure of 2.0 bar to 7.9% for a riser height of 1.5 m and an operating pressure of 1.0 bar [50, 51]. Evaporation and drift losses increased as riser height increased.

The sprinklers should be at the same height, and the nozzles should also be vertical to the surface of the land to move freely for free dispersion of the water droplets. The equipment and design factors, which include the nozzle characteristics such as nozzle size, nozzle type, discharge angle, jet straightening vane inside the main nozzle and the number of nozzles, determine the single-sprinkler distribution patterns [52, 53, 49, 54]. However, wetted diameter is inversely related to wind speed and riser height and directly related to operating pressure [42]. Hence, it is essential to operate the system at low wind speed conditions to satisfy the recommended design overlap of the system.

Low CU% and DU% can be recorded at low pressure and high riser height, which may be caused by the sprinkler's low discharge [39], Additionally, CU% and DU% had a substantial impact on riser height, and as riser height grew, so did the coefficient of uniformity and distribution uniformity. This might be brought on by increased evaporation and drift losses, decreased overlapping effectiveness, and ineffective application uniformity.

Riser height has little or no effect on distribution pattern for wind speed of less than 4 m. p. h [23]. Under actual irrigation practice the type of crop grown will influence the minimum height of riser that can be used. The sprinkler head must be above the vegetative growth of the crop irrigated. The limitations of the maximum height riser will be influenced by the ease of handling the lateral line when moved from one position to another, the tall risers being more difficult to handle [55]. On specialized equipment such as the wheel move laterals, there are also limitations on length of risers that can be used. It is recommended that sprinkler installations be equipped with the tallest riser that can be easily handled by the operator. In addition to the riser height, riser spacing and lateral move are also of significant factors that affect the uniform distribution of sprinkler irrigation. It is recommended that the distance of the lateral move be not greater than 50 percent of the wetted diameter in the direction of the lateral move. The maximum distance of the move would be 26 feet and the actual recommended move would be 20 feet due to standard pipe lengths.

Angle of Wind with Respect to Lateral Line has also an impact on the distribution of irrigation water. The pattern coefficient is significantly different when the angle of wind is different. However, a better pattern seemed to be obtained when the wind angle is between 15 to 45 degrees with the lateral than when the angle was higher or lower. Manufacturers recommend that in design, lateral lines should run perpendicular to the direction of the prevailing wind. Except in certain localized areas, direction of prevailing winds is a meaningless term during the irrigation season. The actual percent of time winds are in the prevailing direction is small. It is of greater importance to the irrigator to make allowances for changes in wind direction from day to day.

Water pressure at riser has also an impact on the distribution of water in sprinkler system equipment and among the factor that affect the uniformity of sprinkler irrigation. Little or no difference of pattern coefficients was obtained between 56 and 48 p. s. i, while a slight difference is obtained between 30 and 40 p. s. i. However, the higher pressures are superior, and the slope of the line is less, indicating that as wind velocities increase the effect of pressure is more prominent. There are indications that pressures greater than 56 p. s. i. would be of little value in obtaining better patterns. When a sprinkler head is operating within the manufacturers recommended range of pressures the increase in uniformity by increasing pressure is not significant enough to verify the increase of pumping costs to obtain this added pressure.

4. Conclusion

For effective utilization of available water resources, effective management is essential. The uniformity of sprinkler irrigation can be attained through effective operation of the equipment and considering feasibility in the environment. Reduction in water resource use can be achieved in sprinkler irrigation by proper selection of irrigation nozzles because most losses are dependent on droplet size, which in turn is influenced by nozzle geometry with regard to nozzle diameter and spray plate configuration.

Generally, the performance of sprinkler irrigation systems is greatly affected by both the direction and magnitude of the wind speed. The height of the riser, mainly in windy areas, the angle of the wind with respect to lateral, and the water pressure at the riser all greatly affect the uniform distribution of sprinkler irrigation. During design, it is better to consider the climatic condition, the topographic feature, and the manufacturer's recommendation.

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