DEVELOPMENT THE PERFORMANCE OF CENTER PIVOT IRRIGATION TO SUIT LOW-PERMEABILITY LANDS

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ABSTRACT

The research aims to improve the performance of center pivot irrigation system by modifying the water outlets on the towers in four different ways, which are (1) fixed sprinkler on the truss rod, (2) dynamic sprinkler bike STD, (3) dynamic sprinkler on the truss rod and (4) single Boom Back system to reach the most suitable water application rate from the sprinklers to suit different types of soil with low permeability to reduce runoff, so the experiment was carried out during season 2023 on a private farm in the New Valley Governorate, Egypt, to study the suitability of the previously mentioned proposed modifications to the center pivot system in terms of the application rate from the sprinklers (under the same speed of the device) and their suitability for different permeability of the soils, and to compare them to the usual center pivot system (without modification) for the same permeability for the previously mentioned soil types.The results were as follows:

1-Average Application rate decreased by increasing the wettedareafor sprinkler (m).

2-An application rate that is more than the soil infiltration rate affects run-off problem.

3-An application rate that is more than the soil infiltration rate affects pivot wet track which casus pivot stuck

4-Using Boom Back solution in the last 2 or 3 towers decreasing the Average application rate by increasing the wettedareafor sprinkler (m).

5-Using dynamic sprinkler with standard fixed drop decreases the application rate when we compare it with the same fixed sprinkler.

6-Adding sprinklers hoses above the truss rod decreasing the application rate and solve the problem on run off and wet wheel track.

Keywords: center pivot, fixed, dynamic, truss rod, Boom Back, runoff

INTRODUCTION

Mohammad and Robert (2015) said that linear and center pivot irrigation systems are becoming more common in America, where runoff due to high application rates of these systems is one of the biggest problems for farmers. Boomback system was done as a solution to reduce runoff to improve the uniformity and efficiency for this system. A field study was conducted in Prosser, Western Australia to compare runoff from Boomback and the standard in-line sprinklers. Both were installed on a single lining irrigation system where the results of this study showed that, compared to the standard system, the Boomback system significantly reduced runoff by up to 26%.

Prossie et al (2014) reported that the main determinant of the design for linear move and center pivot irrigation systemsare soil filtration rates. So, Boomback system has been used to decrease runoff and improve infiltration by decreasing the instantaneous water application rate of linear move and center pivots systems. When compared runoff from a linear move irrigation system (line sprinklers) with offsetboom, system they found that runoff was greater in linear move than Boomback system. The runoff from linear move ranged from 3% to 24% greater than the boom system. Runoff as a percentage of irrigation water applied increased with each irrigation event on both drop types.Infiltration and runoff are important processes that affect the efficiency of center-pivot irrigation systems (Deck et al 2010).

Soil compaction, soil texture, and Vegetation cover were a big effect on the basic infiltration rate Nugroho and Wahyono and Nugroho (2021).Dahak et al., (2022) said that the Horton model, is the most suitable to evaluateInfiltration Rate.Measuring the infiltration characteristicsin field was complicated taskanda time-consumingforagriculture researchersandwater resourceSingh et al., (2021). Harisuseno and Evi (2020) illustrated that porosity of soil mostly contributes to the regression equation that indicates big effect to control the soil infiltration rate behavior.

The management practices and land uses affected the accuracy for the selected infiltration models (Failache and Lázaro 2021).

Sprinkler packages are selected and designed for many reasons, for example high application efficiency and irrigation uniformity are priority goals in selecting a sprinkler application method or particular sprinkler package. In the field, many sprinkler packages can achieve the design and operational goals equally well at or near the same costs. Maintenance, management, and even installation factors are very important as the application method or the selection of a package Howell (2003).

Moving irrigation systems, especially center pivot irrigation, are designed to apply the water over a given point in field within in a certain amount and at a specified time. When the application rate of water is greater than the rate of soil infiltration and soil surface storage, water begins to flow on the surface of the runoff soil (Mielke et al., 1992; Luz and Heermann, 2004).

Many factors depend on the infiltration rate, including type of soil, soil surface coverage and moisture content of the soil.Surface storage allows water to stand on the surface temporarily until completely infiltrated. The soil surface storage capacity depends on slope of the field, the type of crops and soil surface conditions in this field. Increasing the amount of soil surface storage can prevent or reduce the Runoff (Nepling et al., 2009).

To minimize runoff, this can be done by reducing the application rate of water while maintaining the desired depth of irrigation requirements for crop. BoomBack or linear moves on the center pivot system are one of the most important ways to reduce the application rate of water (King and Kincaid, 1997).

The objective of this work was development the performance of center pivot irrigation by doing modifications in the outlet of water to reduce runoff under all of it to suit low-permeability lands.

MATERIAL AND METHODS

The experiment was carried out during season 2023 on a private farm in the New Valley Governorate, Egypt, to study the suitability of modifying the water outlets on the spans for center pivot system in terms of the application rate from the sprinklers (under the same speed of the device) and their suitability for different permeability of the soils, to compare them with the usual center pivot system (without modification) for the same permeability for the soil types. This will be done through the treatments shown in Table (1) and Table (2).

Table 1. Treatments of modifications for-center pivot irrigation systems.

Treatments of modifications				
Control	C_1	C_2	C_3	C_4
Center pivot (Fixed Sprinkler STD)	fixed sprinkler on the single truss rod	dynamic sprinkler bike STD	dynamic sprinkler on the single truss rod	Boom-back system

Table 2. Treatments of permeability of the soils (Basic infiltration rate of soil).

Treatments (Types of soil)				
Treatments	Soil NO.1	Soil NO.2	Soil NO.3	Soil NO.4
Basic infiltration rate of soil	P_1	P_2	P_3	P_4

The application rate of irrigation system (A.R)

Application rate is the volume of water applied to a location during a specified period. Ideally, the irrigation application rate would be matched to the steady state soil rate. Assuming dry soil, the infiltration rate for soil is high at the initiation of water application and decreases as infiltration continues until it reaches a stable (steady state) rate. If the water application rate is less than the soil steady state infiltration rate, the irrigation water should be able to be infiltrated into the soil root zone. However, this design criterion was developed when the sprinkler packages were primarily high-pressure, large wetted diameter impact sprinklers. The term application rate can also refer to several different measurements. The instantaneous application rate refers to the rate of water application at any given time. This value will vary from zero to the peak instantaneous application rate as the water delivery package crosses over a given point. The peak application rate generally refers to the maximum application rate for a system. The mean application rate would be the volume of water delivered at a given point during the total time of wetting and would be a smaller value than the peak application rate. The application rate for various nozzles must increase with distance from the pivot point as more area is covered by the nozzle with distance. This is why runoff problems are generally associated with the outer edges of a center pivot unless soil or slope conditions are more limiting in an inner portion of the center pivot as the figure (1) shows that the water application rate towards the end of the system (from first to last span) might become critical if it exceeds the soil infiltration rate.

Application rate of irrigation system (A.R) is a measure of the application rate from all the points within irrigation system was calculated from the following equation.

$$A.R = \frac{Q * L}{0.4417 * D}$$

Where:

A.R:Application rate (mm/hr.)

Q:Flow rate (l/s per Hectar).

L:Pivot length (m).

D:Sprinkler throw diameter (m).

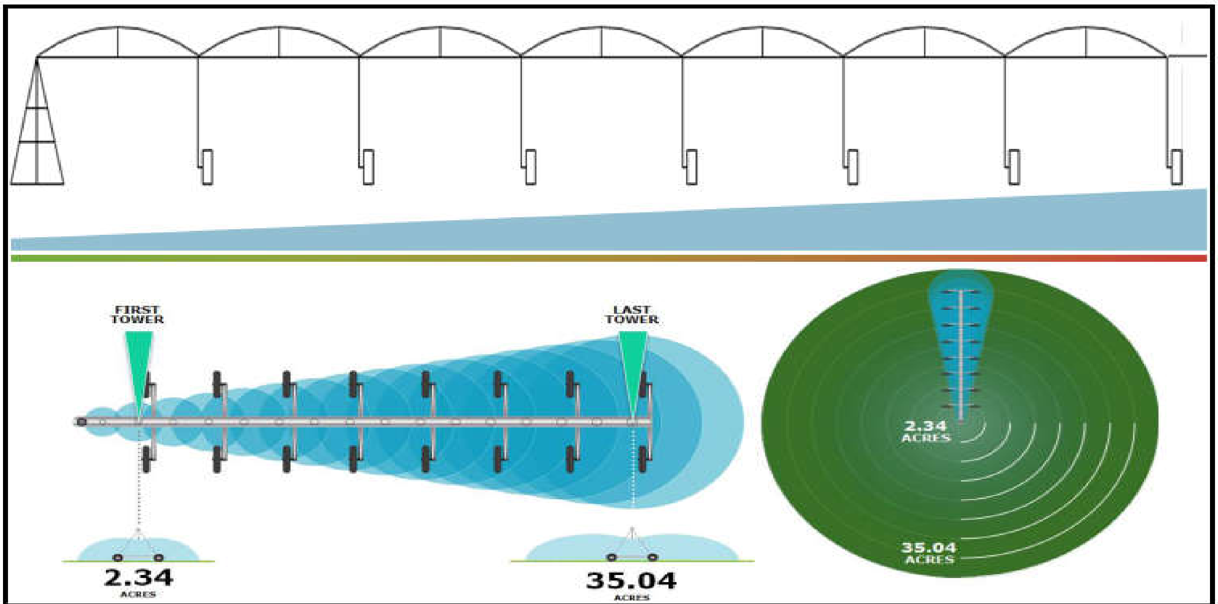


Figure 1. Graph shows the water application rate along center pivot which increasing from first to last span.

Specificationof center pivot irrigation system CC (Control)

Table (3) showed the specification of the center pivot system, control, table (4) showedthe application rate of irrigation system is a measure of the application rate from all the points within the irrigation system under treatment by using Fixed Sprinkler STD (Komet KPS - FL33 Black) where the average application rate in the last tower is 85.2 mm/hr. also figure (2) shows design of water outlet under one span with Fixed Sprinkler STD (control).

Table 3. Specification of center pivot irrigation system (control).

Pivot length (m)	Pivot flow rate (m^3/hr.)	Pressure regulator (psi)	Pivot Base pressure (psi)	Pivot end pressure (psi)	Sprinkler type	Sprinkler throw diameter (m)
394m (7 Span * 56.1m)	260	15	40	20	KPT & KPS Komet Sprinkler	15

Table 4. Average application rate with Fixed Sprinkler STD (control).

Number of Span	T1	T2	T3	T4	T5	T6	T7
Length of one span (m)	57.4	56.1	56.1	56.1	56.1	56.1	56.1
Length from zero to the next span (m)	57.4	113.5	169.6	225.7	281.8	337.9	394
Average Span Application Rate (mm/h)	11.8	26.9	41.1	54.4	67.3	79.5	**85.2**

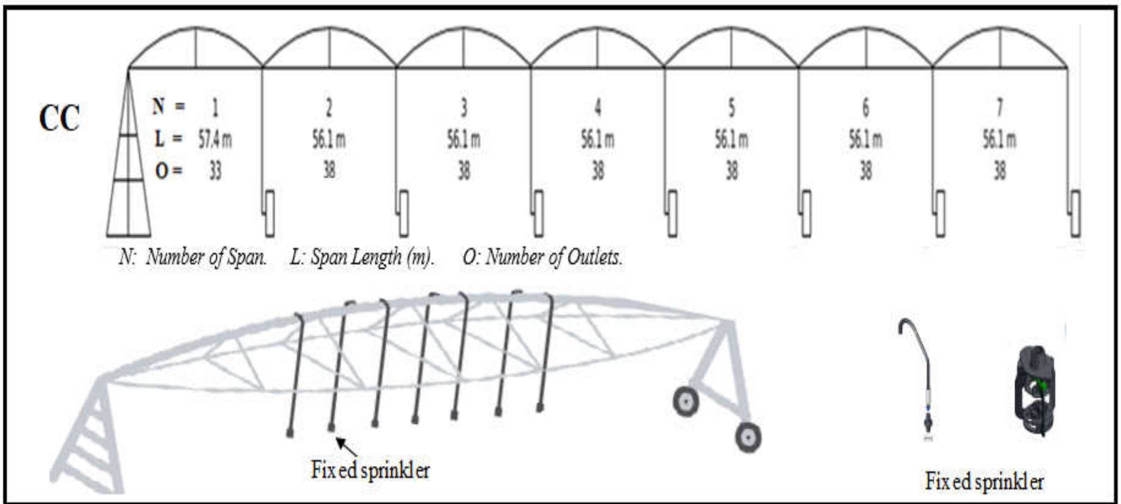


Figure 2. Design of water outlet under CC treatment (Fixed Sprinkler STD (control)

The modification in the water outlet

There are four different modifications to the water outlets on the center pivot irrigation system, which are as follows:

1. **First modification (fixed sprinkler on single truss Rod (C_1)**

Table (5) showed the specification of the first modification in the water outlet of the center pivot system which was a fixed sprinkler on single truss Rod (C_1), and the application rate of irrigation system is a measure of the application rate from all the points within the irrigation system where the average application rate in the last tower is 73.4 mm/hr and the graph in figure (3) showeddesign of water outlet and the wetted area under one span.

Table 5. Average application rate with Fixed Sprinkler on single truss rod (C_1).

Number of Span	T1	T2	T3	T4	T5	T6	T7
Length of one span (m)	57.4	56.1	56.1	56.1	56.1	56.1	56.1
Length from zero to the next span (m)	57.4	113.5	169.6	225.7	281.8	337.9	394
Average Span Application Rate (mm/h)	9.4	22.2	34.3	45.8	57	67.9	**73.4**

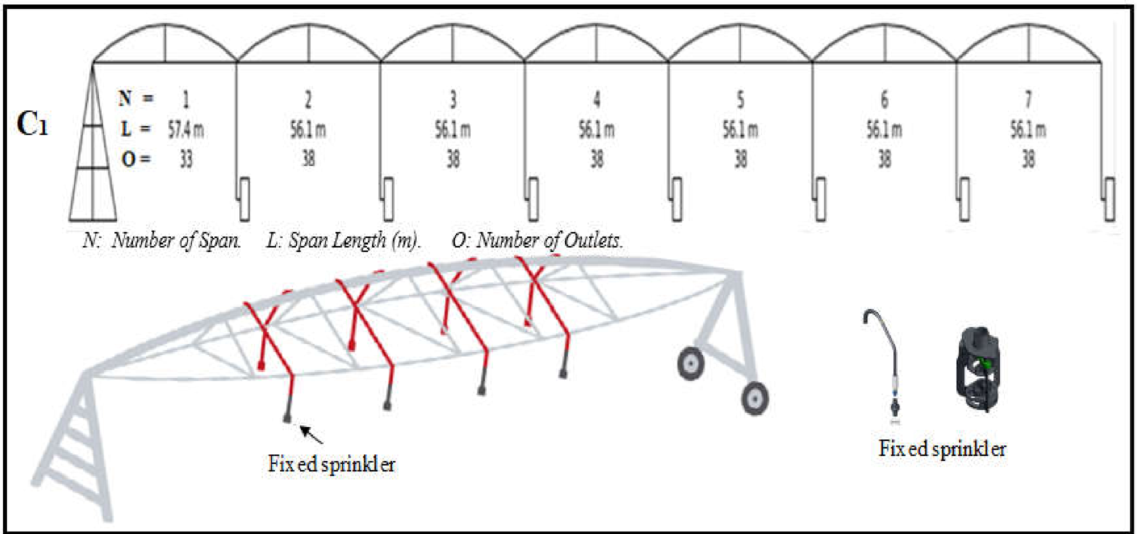


Figure 3 .design of water outlet under C1 treatment (fixed sprinkler on the truss rod)

2. Second modification (dynamic sprinkler bike STD (C2)

Table (6) showed the specification of the second modification in the water outlet of the center pivot system which was a dynamic sprinkler bike STD (C_2), and the application rate of irrigation system is a measure of the application rate from all the points within the irrigation system under treatment by using dynamic sprinkler bike STD where the average application rate in the last tower is 70.7 mm/hr. andthe graph in figure (4) showed design of water outlet under one span.

Table 6. Average application rate with dynamic sprinkler bike STD (C_2).

Number of Span	T1	T2	T3	T4	T5	T6	T7
Length of one span (m)	57.4	56.1	56.1	56.1	56.1	56.1	56.1
Length from zero to the next span (m)	57.4	113.5	169.6	225.7	281.8	337.9	394
Average Span Application Rate (mm/h)	7.1	18.2	27.7	40.5	49.8	64.2	**70.7**

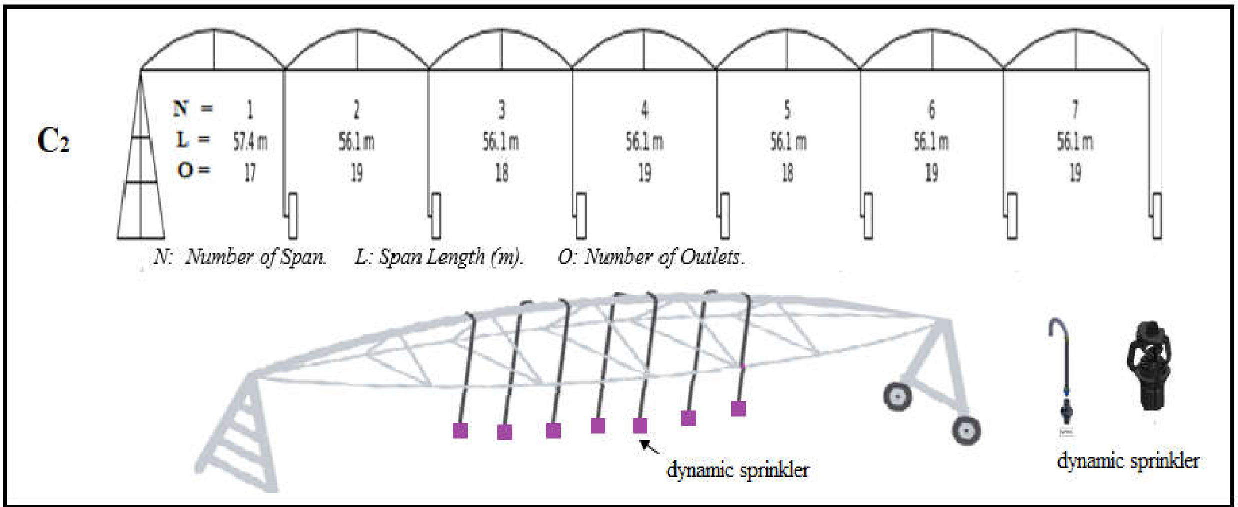


Figure 4. Design of water outlet under C2 treatment (dynamic sprinkler bike STD)

3. Third modification (dynamic sprinkler on single truss rod (C_3))

Table (7) showed the specification of the second modification in the water outlet of the center pivot system which was a dynamic sprinkler on single truss rod (C_3), and the application rate of irrigation system is a measure of the application rate from all the points within the irrigation system under treatment by using dynamic sprinkler on single truss rod (C_3), where the average application rate in the last tower is 63 mm/hr. and the graph in figure (5) showed design of water outlet under one span.

Table 7. Average application rate with dynamic sprinkler on single truss rod (C_3).

Number of Span	T1	T2	T3	T4	T5	T6	T7
Length of one span (m)	57.4	56.1	56.1	56.1	56.1	56.1	56.1
Length from zero to the next span (m)	57.4	113.5	169.6	225.7	281.8	337.9	394
Average Span Application Rate (mm/h)	6.2	16.1	24.6	36	44.2	56.8	**63**

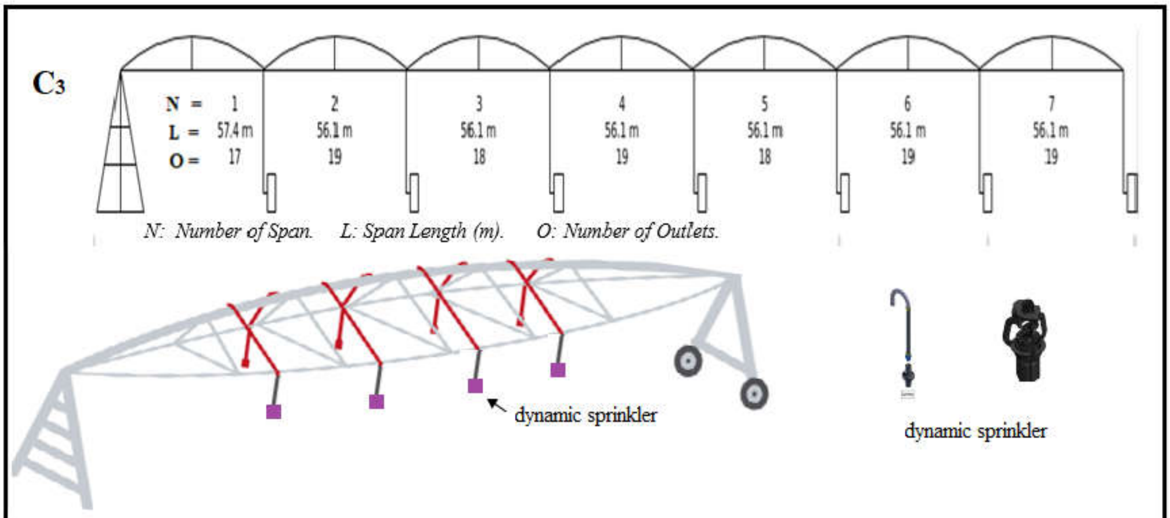


Figure 5. Design of water outlet under C_3 treatment (dynamic sprinkler on single truss rod)

4. **Fourth modification single Boom Back suspension system (C4)**

Table (8) showed the specification of the second modification in the water outlet of the center pivot system which was a single Boom Back suspension system (C_4), and the application rate of irrigation system is a measure of the application rate from all the points within the irrigation system under treatment by using single Boom Back suspension system (C_4), where the average application rate in the last tower is 45.3 mm/hr. and the graph in figure (6) showed design of water outlet under one span.

Table 8. Average application rate with single Boom Back suspension (C_4).

Number of Span	T1	T2	T3	T4	T5	T6	T7
Length of one span (m)	57.4	56.1	56.1	56.1	56.1	56.1	56.1
Length from zero to the next span (m)	57.4	113.5	169.6	225.7	281.8	337.9	394
Average Span Application Rate (mm/h)	4.1	11.1	17.3	25.2	31	39.3	**45.3**

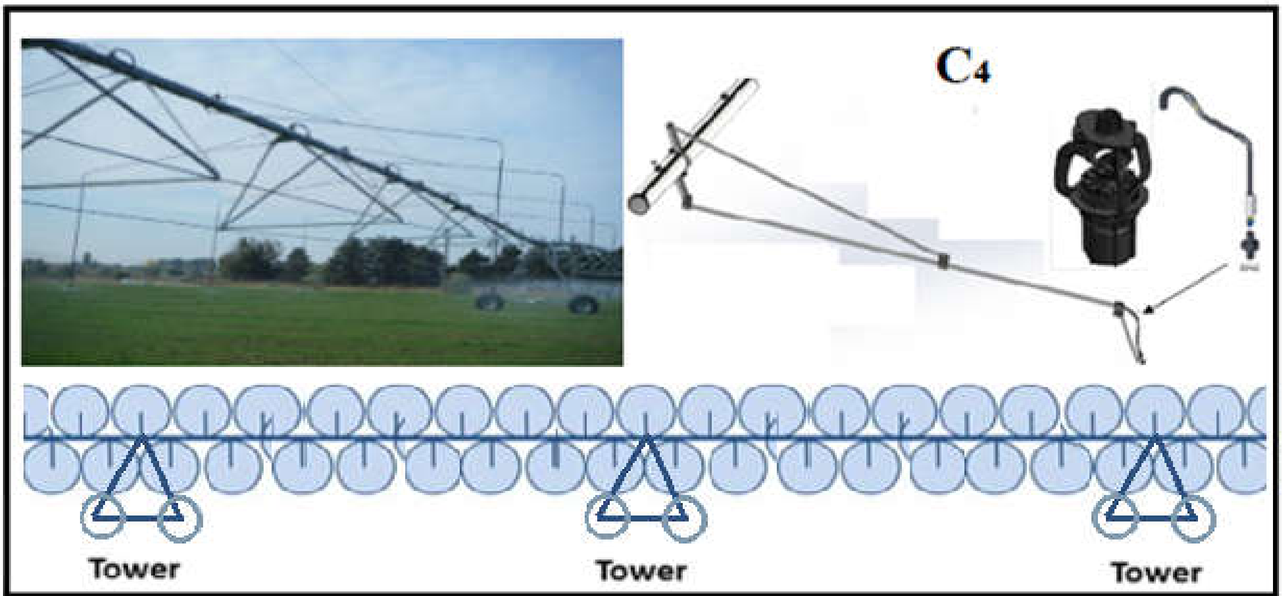


Figure 6. Design of water outlet under C_4 treatment (Single Boom Back system)

Infiltration rate of soil

The infiltration rate is the velocity or speed at which water enters the soil. It is usually measured by the water layer's depth (in mm) that can enter the soil in one hour. In dry soil, water infiltrates rapidly. This is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic infiltration rate.

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure and is a useful way of categorizing soils from an irrigation point of view. The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer (figure 7). Figure (8) shows the Infiltration rate curves from the USDA Natural Resources Conservation Service for various soil intake families (USDA NRCS, 1997).

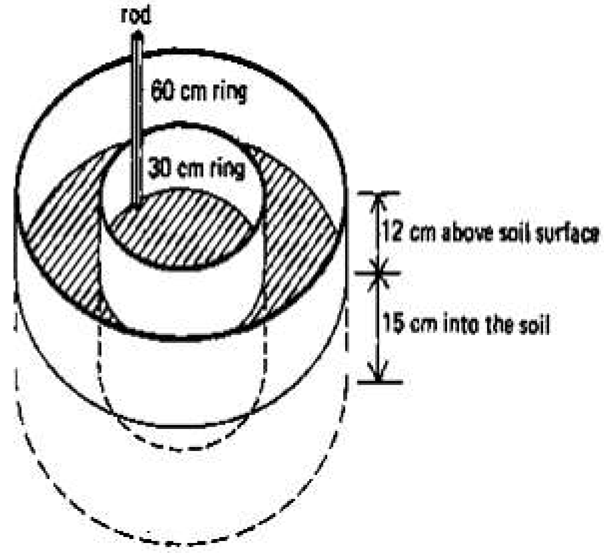


Figure 7. Cylinder or ring infiltrometer.

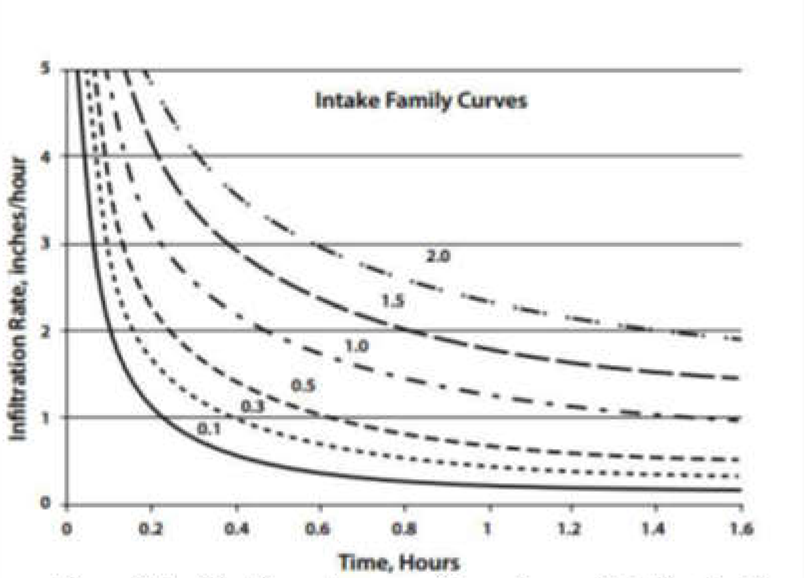


Figure 8. Infiltration rate curves for various soil intake families.

RESULTS AND DISCUSSION

The results in this research will include on three indicators under all the previous modification of treatments with the same speed of device:

1- Infiltration rate. 2- Application rate. 3- Run-Off in the soil.

1- Infiltration rate

Infiltration of irrigation water onto the soil surface is the most important factors influencing the selection of the suit irrigation method and increasing its efficiency, as it determines the rate of water flow over the soil surface and the rate of its precipitation to the surface, and thus the net depth of irrigation water reaches the root zoon (mm/hour) and the total precipitation depth is the depth of water that infiltration the soil surface from the beginning of the time period this is large at the beginning of irrigation and then decreases until it reaches a fixed value called (basic soil infiltration rate). The sprinkler irrigation rate (for example) must not exceed the basic filtration rate.

Basic infiltration rate under all treatments

Data in figure (9) showed the relationship between the cumulative infiltration rate (mm/hr.) and cumulative time (minute) in the field where Basic infiltration rate under treatments (P_1, P_2, P_3 and P_4) were 1, 1.4, 2 and 3.2 mm/h respectively.

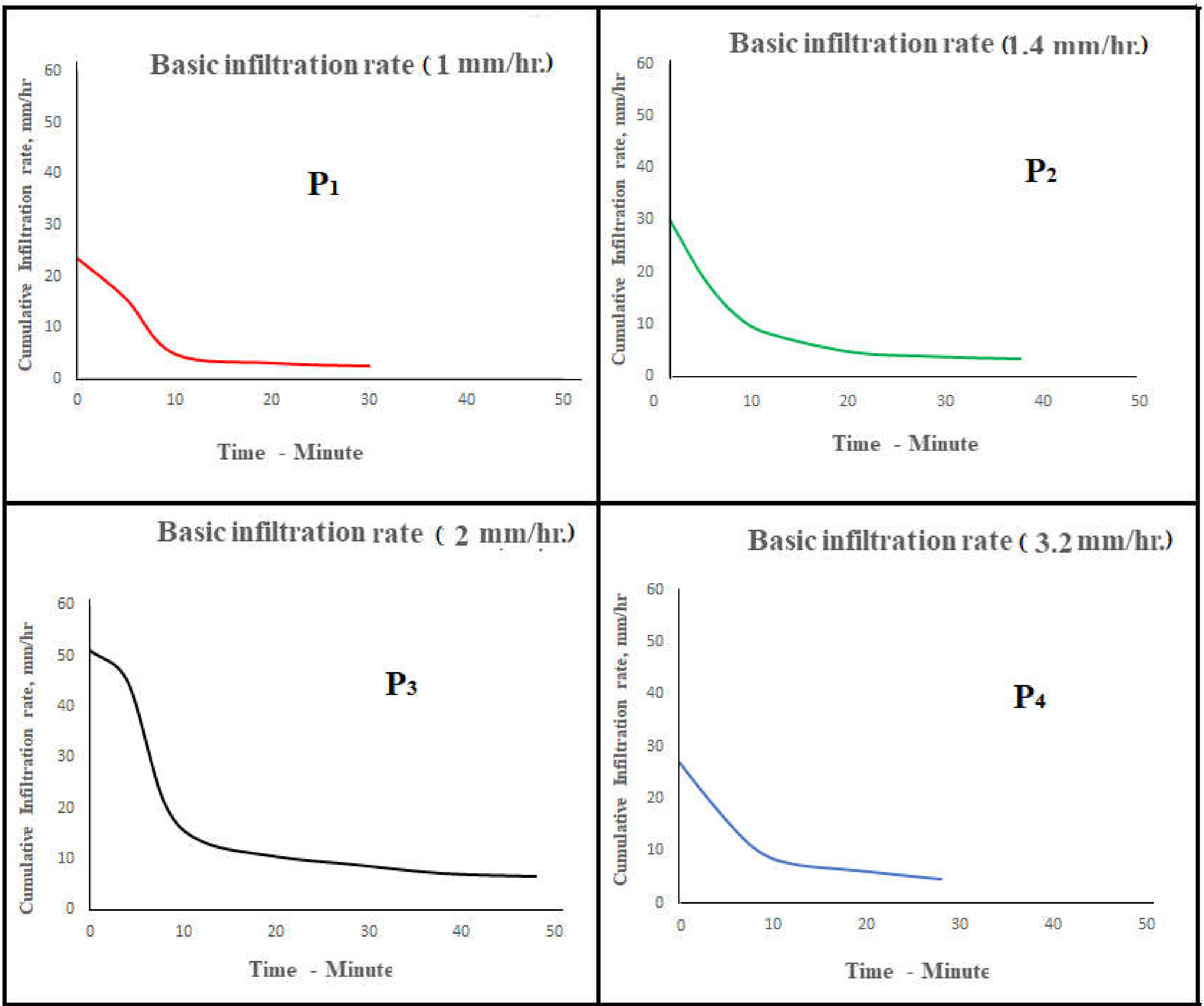


Figure 9 . the cumulative infiltration rate (mm/hr.) under all treatments

2- <u>The application rate of irrigation system (A.R)</u>

Data in figures 10 and 11 showed that average application rate under each span with CC treatment, control, (Fixed Sprinkler STD) was 11.8 mm/hr. in the first of span and increased to reach in the last span to 85.2 mm/hr. while with C_1 treatment (Fixed Sprinkler with single truss rod) was 9.4 mm/hr. in the first of span and increased to reach in the last span to 73.4 mm/hr., with C_2 treatment (Dynamic Sprinkler STD) was 7.1 mm/hr. in the first of span and increased to reach in the last span to 70.7 mm/hr., with C_3 treatment (Dynamic Sprinkler STD with single truss rod) was 6.2 mm/hr. in the first of span and increased to reach in the last span to 63 mm/hr., with C_4 treatment (single Boom Back suspension) was 4.1 mm/hr. in the first of span and increased to reach in the last span to 45.3 mm/hr.

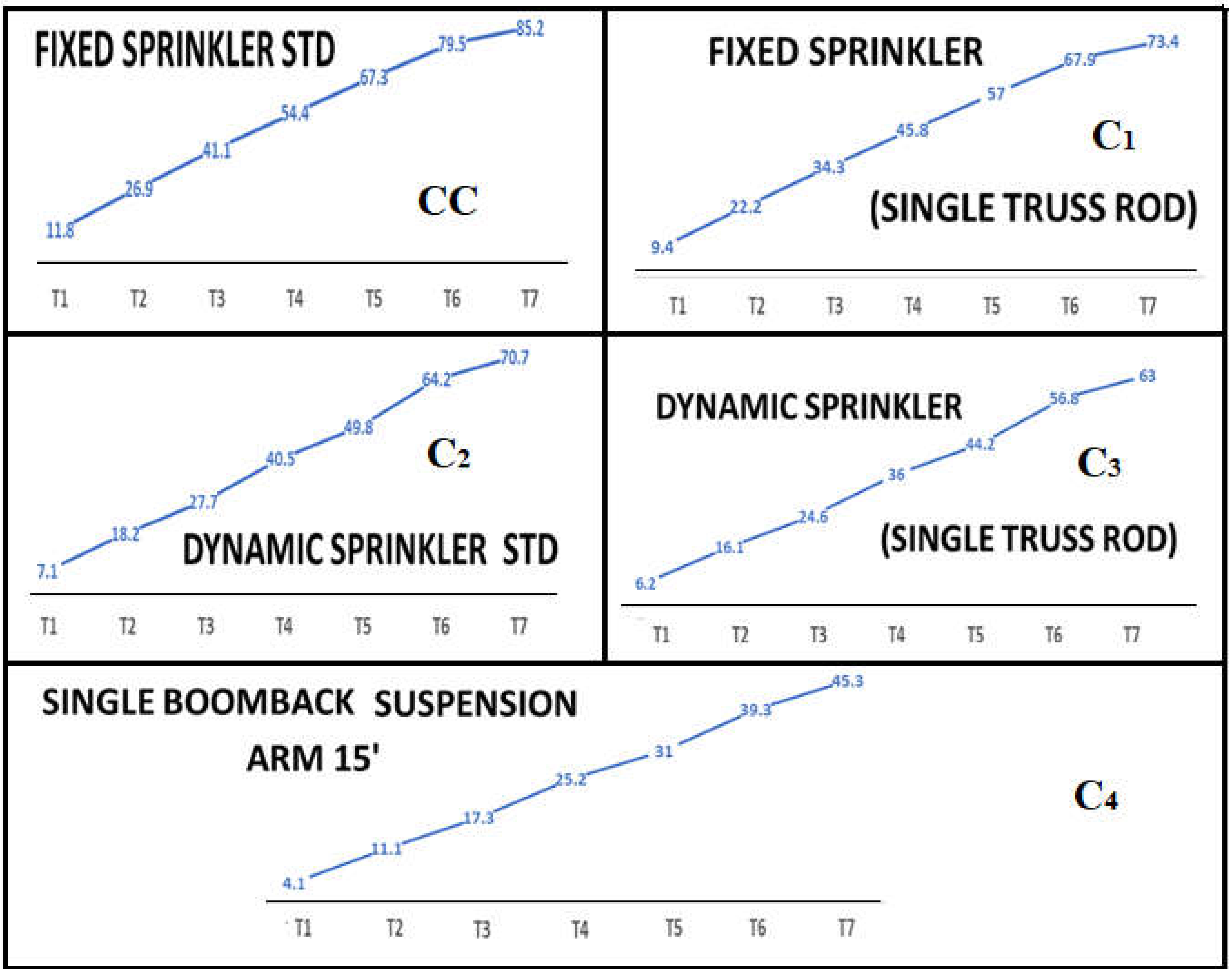


Figure 10. Application rate (mm/h) with each span under all treatments.

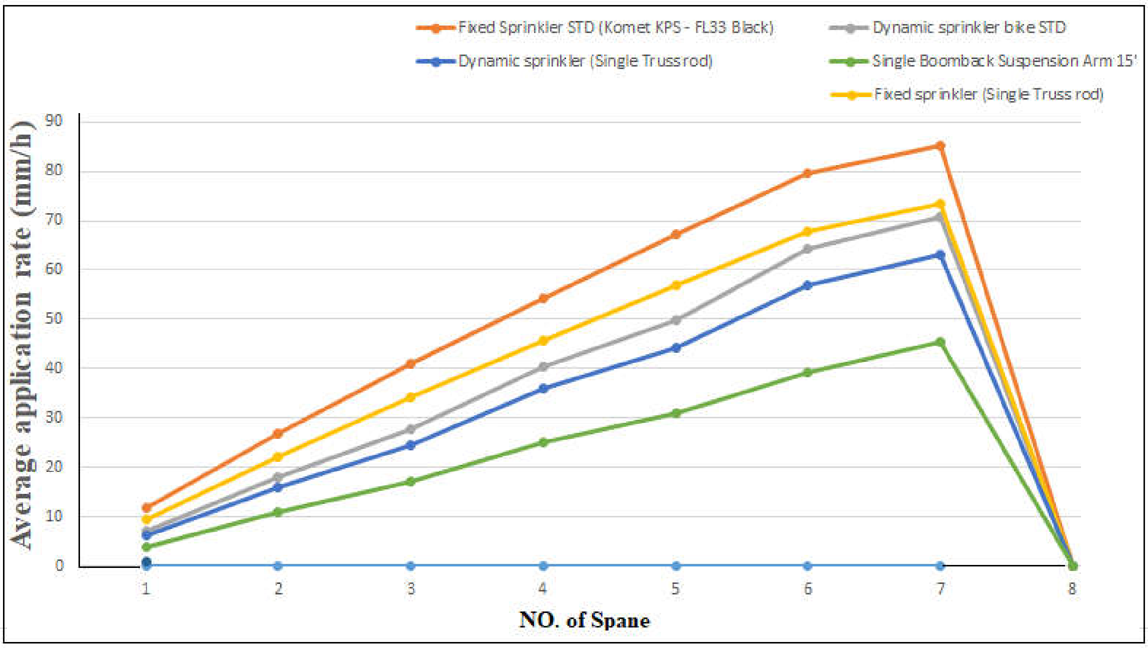


Figure (11). Average application rate (mm/hr.) for all treatments alongside the pivot for each span

It was noticed that the increasing in the application rate alongside the pivot due to increasing the area in the last span from the beginning to the last span.

Generally, Data in figures (12,13,14,15 and 16) showed wetted area with all treatments which increased, with decreasing application rate, by using dynamic sprinkler (C_2), by adding sprinkler on the truss rod (C_3) and by adding Boom Back system (C_4).

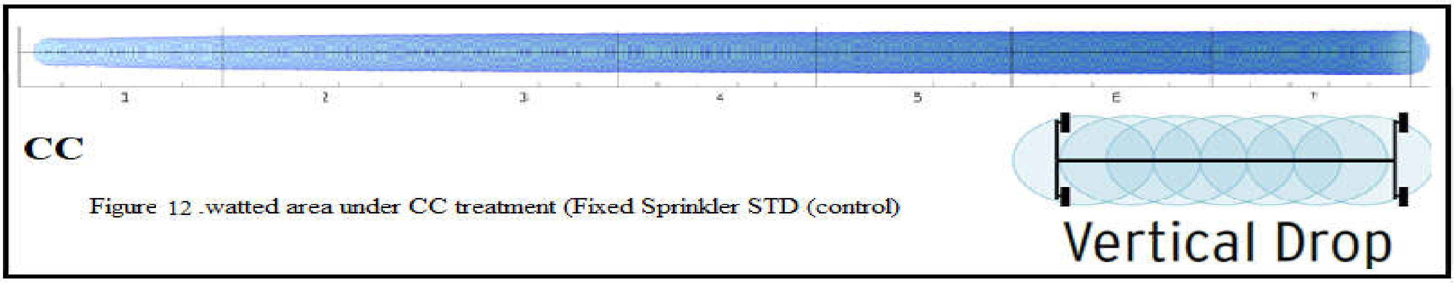


Figure 12 .watted area under CC treatment (Fixed Sprinkler STD (control)

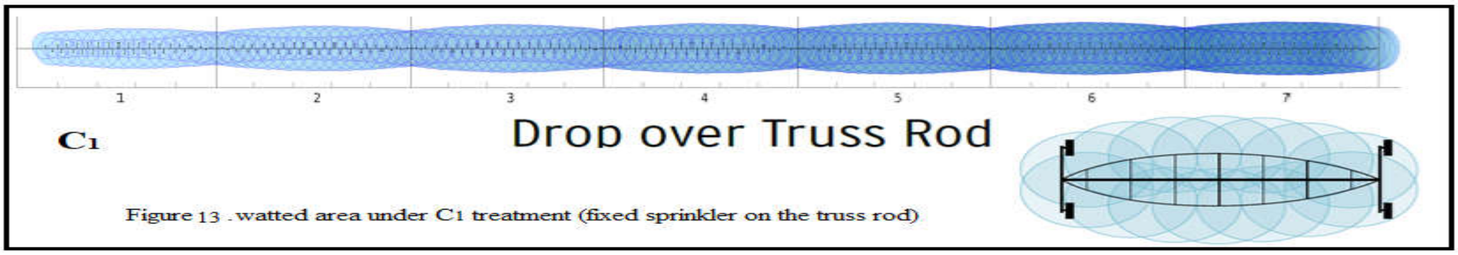


Figure 13 .watted area under C1 treatment (fixed sprinkler on the truss rod)

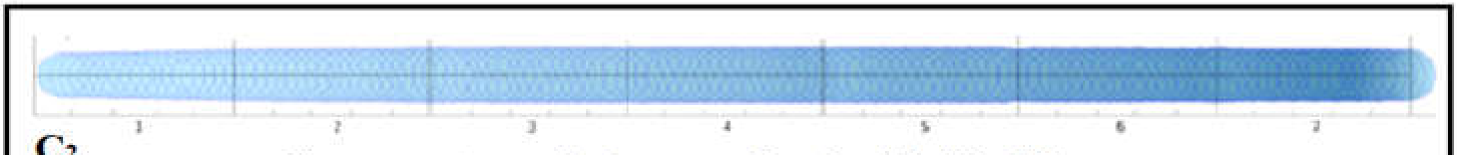


Figure 14. watted area under C2 treatment (dynamic sprinkler bike STD)

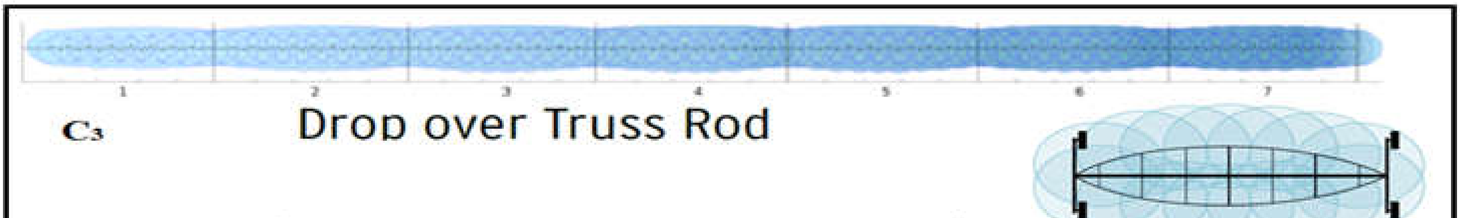


Figure 15 . watted area under C3 treatment (dynamic sprinkler on single truss rod)

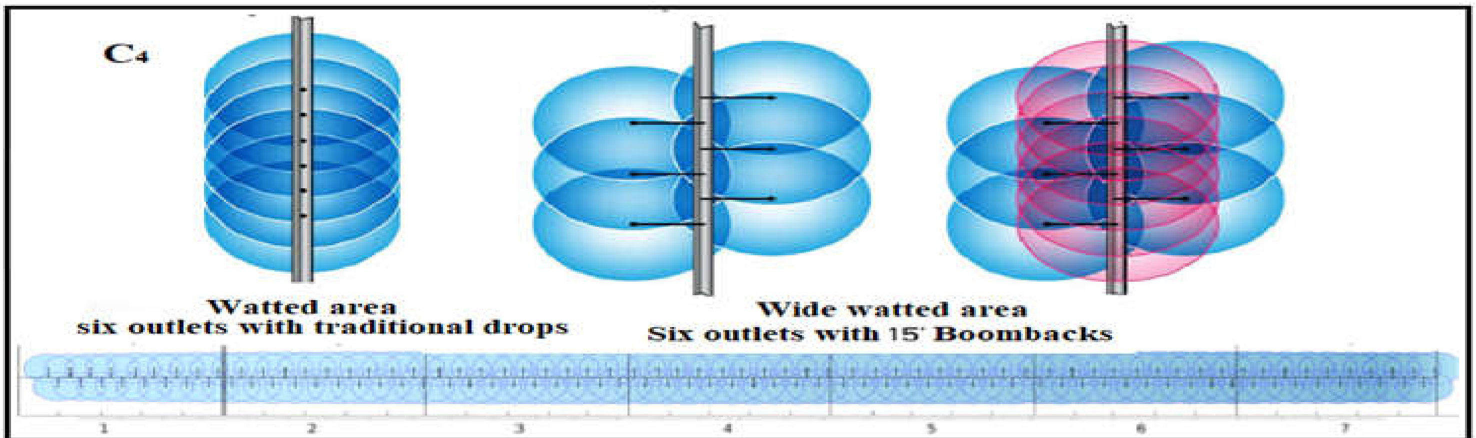


Figure 16 . watted area under C4 treatment (Single Boom Back system)

3- Run-Off in the soil

Data in figures(17 and 18) show the run-off curve as a result of intersection and overlapbetween the cumulative application rate curve and cumulative infiltration rate curve, where the major design of all modifications aim to reduce or prevent Run-off specially in the last span which has a higher application rate due to increasing the area in last span.

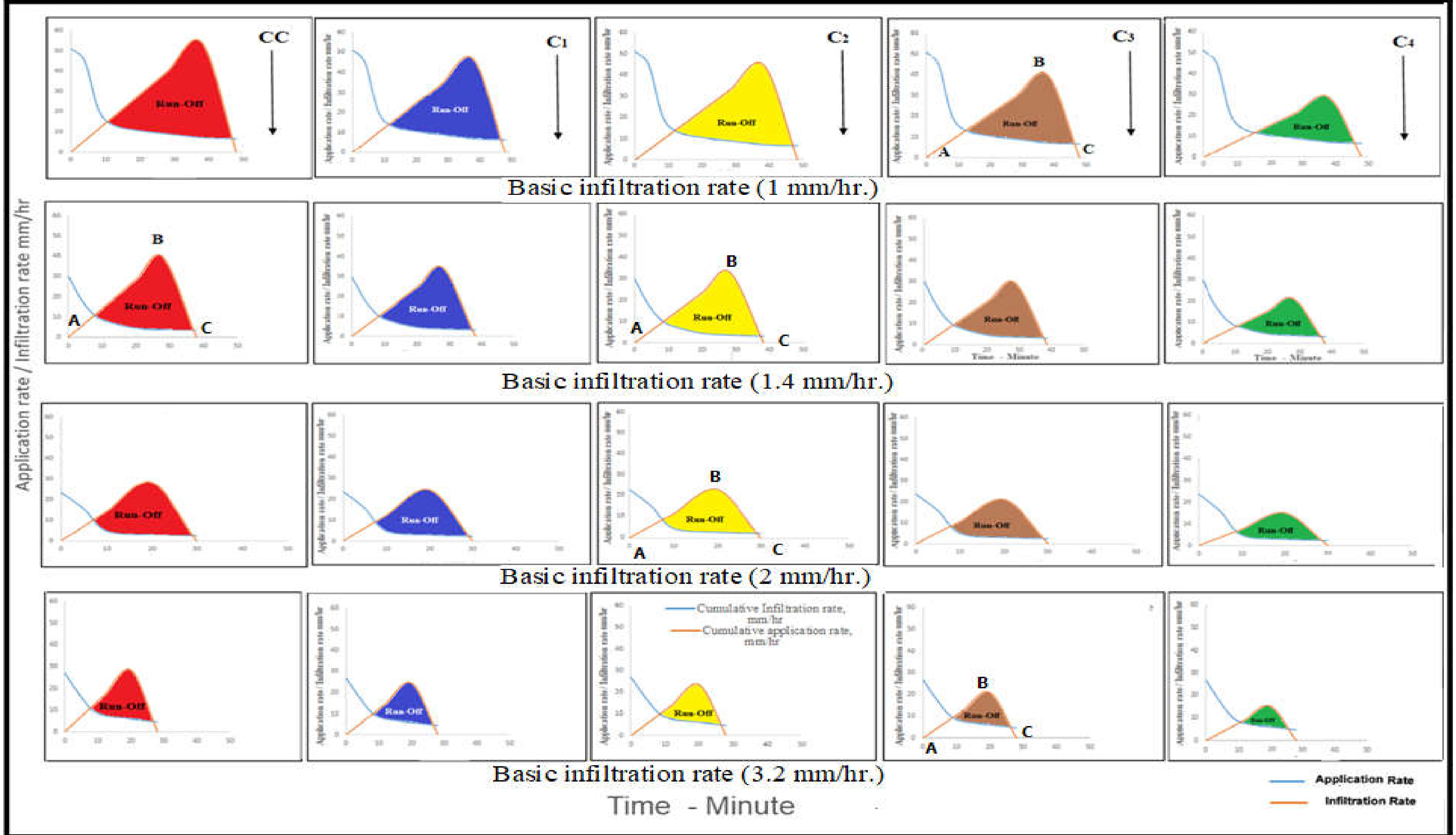
Data in figure (17) showed that, under **CC treatment** (with Fixed Sprinkler STD), Run-off was low with the soil which basic infiltration rate was 3.2 mm/hr. and Run-off decreased when the basic infiltration rate increased to 1, 1.4 and 2 mm/hr. respectively.

While data in figures 17 and 18 under **C_1 treatment** (with fixed sprinkler on the truss rod), **C_2 treatment** (with dynamic sprinkler bike STD), **C_3 treatment** (with dynamic sprinkler on the truss rod) and **C_4 treatment** (with single boom back system) respectively showed that Run-off took the same trend with **CC treatment** (with Fixed Sprinkler STD) where Run-off was low with the soil which basic infiltration rate was 3.2 mm/hr. and Run-off decreased when the basic infiltration rate increased to 1, 1.4 and 2 mm/hr. respectively.

Data also showed that Run-off, under the same permeability of soil, was low with **C_4 treatment** (with single boom back system) compared to **C_3 treatment** (with dynamic sprinkler on the truss rod), **C_2 treatment** (with dynamic sprinkler bike STD), **C_1 treatment** (with fixed sprinkler on the truss rod), and **CC treatment** (with Fixed Sprinkler STD respectively.

On the other hand, data in figure (17and 18) showed that, with the same basic infiltration rate, Run-off was low under C_4 treatment (with single boom back system) and increased under C_3 treatment (with dynamic sprinkler on the truss rod) C_2 treatment (with dynamic sprinkler bike STD) C_1 treatment (with fixed sprinkler on the truss rod) and CC treatment (with Fixed Sprinkler STD) respectively.

Generally, with the same basic infiltration rate, Run-off was lower under C_4 treatment (with single boom back system) and was higher with CC treatment (with Fixed Sprinkler STD) due to the application rate for all treatments alongside of the pivot was proofing that Sprinkler packages with a higher wetted radius have a lower application rate and therefore are less likely to produce runoff (figures 12, 13, 14,15 and 16).



A: represents the start of the irrigation, C: is the completion of the irrigation.
B: is the peak application rate (usually when the system is directly overhead)

Figure. (17). Run-Off under with all treatments.

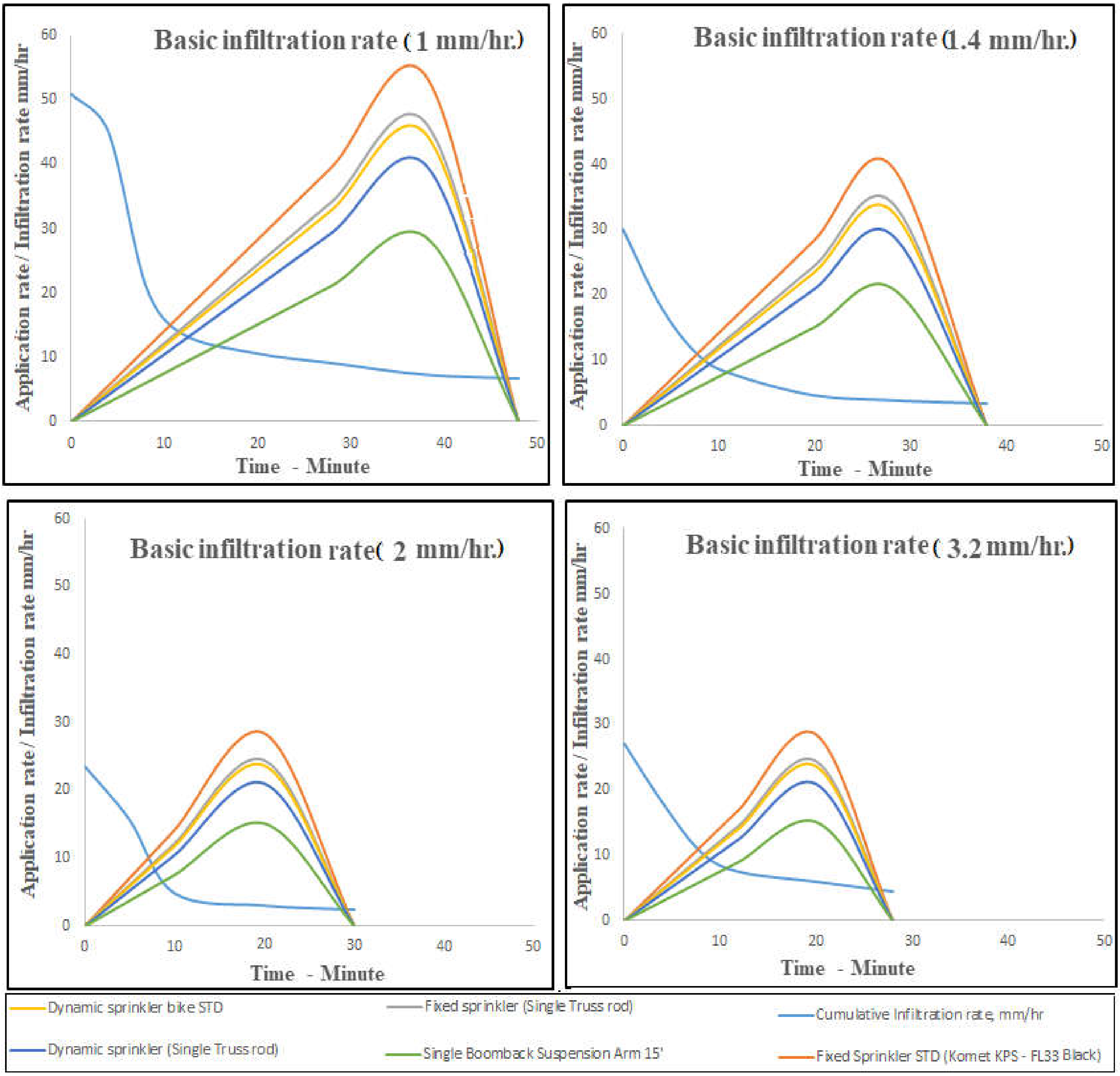


Figure 18. Soil infiltration rat, application rate and runoff for all treatments alongside the pivot

CONCLUSION:

Center pivot systems are popular because of the ability to provide efficient and uniform application of irrigation water for a wide variety of crops and field conditions when equipped with a properly designed and operated water delivery package. Center pivot labor requirements also tend to below as compared to surface irrigation system requirements.

There are many different water delivery package options associated with center pivot irrigation systems, and consideration must be given to the overall system rather than to "fixing" one problem. A trend in recent years has been to use low pressure nozzles which reduces the overall pressure required for the system, to help reduce operating costs. Since lower pressure nozzles have a smaller droplet size, they are more susceptible to drift and evaporation losses. Lower pressure nozzles also increase the average application rate, increasing the potential for runoff. The capacity needed to effectively water a given field may not be met by a system whose pressure has been reduced solely for the purpose of reducing pumping costs. This is a good example of how focusing on one aspect of the system can lead to other problems elsewhere on the system. When designing a new system or converting an older system, consideration should be given to the general nozzle performance requirements as well as to cost reduction and water loss reduction. The research's findings can be summarized below.

1-Average Application rate decreased by increasing the wettedareafor sprinkler (m).

2-An application rate that is more than the soil infiltration rate affects run-off problem.

3-An application rate that is more than the soil infiltration rate affects pivot wet track which casus pivot stuck

4-Using Boom Back solution in the last 2 or 3 towers decreasing the Average application rate by increasing the wettedareafor sprinkler (m).

5-Using dynamic sprinkler with standard fixed drop decreases the application rate when we compare it with the same fixed sprinkler.

6-Adding sprinklers hoses above the truss rod decreasing the application rate and solve the problem on run off and wet wheel track.

Recommendation

Therefore, applications of Boomback system are highly recommended especially when farmers deal with soil with low infiltration rates.

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