# PERFORMANCE EVALUATION OF FURROW IRRIGATION SYSTEM FOR BRINJAL WITH DIFFERENT MULCHES

**M. Tech. (Agril. Engg.)**

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# PERFORMANCE EVALUATION OF FURROW IRRIGATION SYSTEM FOR BRINJAL WITH DIFFERENT MULCHES

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**by**

**Manisha Lilhare**

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## CERTIFICATE - I

This is to certify that the thesis entitled **"Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Manisha Lilhare** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

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Date: 23.07.16

### THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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# CERTIFICATE – II

This is to certify that the thesis entitled **“Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches”** submitted by **Manisha Lilhare** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of **Soil and Water Engineering** has been approved by the external examiner and Student’s Advisory Committee after oral examination.

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*Place : Raipur*

Milhare

*Date :* 18/07/016

*(Manisha Lilhare)*

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# LIST OF NOTATIONS/SYMBOLS

| **Symbol** | **Description** |
|---|---|
| % | Per cent |
| & | And |
| < | Less then |
| @ | At the rate of |
| °C | Degree Centigrade |
| cm | Centimeter |
| avg. | Average |
| cm | Centimeter |
| db | Dry basis |
| dia. | Diameter |
| $eq^n$. | Equation |
| gm | Gram |
| H | Hour |
| ha | Hectare |
| ha/h | Hectare per hour |
| h/ha | Hour per hectare |
| i.e. | That is |
| kg | Kilogram |
| kg/h | Kilogram per hour |
| kg/ha | Kilogram per hectare |
| kg/s | Kilogram per second |
| $kg/cm^3$ | Kilogram per centimeter cube |
| LHS | Left Hand Side |
| m | Meter |
| Mg | Milligram |
| mg/ha | Milligram per hectare |
| mm | Millimeter |
| min. | Minute |
| $\eta_e$ | Field efficiency |
| $m^2$ | Square meter |
| RHS | Right Hand Side |
| t/ha | Tons per hectare |
| viz. | Namely |
| Wb | Wet basis |
| wt. | Weight |

# LIST OFABBREVIATIONS

| Abbreviations | Description |
|---|---|
| Agril. Engg. | Agricultural Engineering |
| AICRP | All India Coordinated Research Project |
| Avg. | Average |
| M.Tech. | Master of Technology |
| CIAE | Central Institute of Agricultural Engineering |
| Fig. | Figure |
| ICAR | India Council of Agricultural Research |
| AAI | Allahabad Agriculture Institute |
| Agril. | Agricultural |
| Engg. | Engineering |
| IGKV | Indira Gandhi Krishi Vishwavidyalaya |
| MSL | Mean Sea Level |
| RH. | Relative Humidity |
| P.P. | Physiological Parameters |
| FYM | Farm Yard Manure |

# THESIS ABSTRACT

| | | |
|---|---|---|
| a) | Title of the Thesis : | Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches |
| b) | Full Name of the Student: : | Manisha Lilhare |
| c) | Major Subject: : | Soil and Water Engineering |
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| e) | Degree to be Awarded: : | Master of Technology in Agricultural Engineering |

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Signature of Major Advisor

22/07/2016

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Signature of Head of the Department

# ABSTRACT

A field study was conducted "Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches" during 2014-2015, at demonstration field of faculty of agricultural engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The experiment comprised of five treatments including furrow irrigation with black plastic mulch ($T_1$), furrow irrigation with straw mulch ($T_2$), furrow irrigation with saw dust mulch ($T_3$), furrow irrigation with soil mulch ($T_4$) and furrow irrigation without mulch ($T_5$) 2 lps stream size was used for irrigation in all the five treatments. In the study, observations related to flow hydraulic of furrow irrigation with different mulches in brinjal were taken. Economic analysis brinjal were taken. Economic analysis of the production system in each treatment was also made. The results revealed that advance and recession curve in furrow irrigation system were almost parallel with stream size of 2lps. Parallelism of curves ensured uniform distribution of water. The net depth of water applied was found 5.248 cm, gross depth of water applied was found 6.997 cm and actual depth of water applied in each irrigation was found 6.85 cm. Basic infiltration rate of experimental soil in each treatment varied as 0.44, 0.62, 0.6, 0.48 and 0.46 (1st irrigation), 0.56, 0.62, 0.64, 0.52 and 0.52 (2nd irrigation), 0.58, 0.6, 0.66, 0.52 and 0.5 (3rd irrigation,). Soil moisture content after 1st, 2nd and 3rd irrigation in each treatment was the highest in black plastic mulch and minimum in without mulch. The application efficiency in the treatment $T_1$ was distinctly much higher in comparison to other treatments. The lowest application efficiency was found in $T_5$ i.e. furrow irrigated system without any mulch. Distribution efficiency was also highest in treatment $T_1$ and lowest distribution efficiency in treatment $T_5$. The total cost of cultivation was highest in treatment $T_1$ due to relatively higher cost of plastic mulch. The lowest cultivation cost was found in treatment $T_5$ as no mulching cost was involved and the labour requirement was also lowest. The yield of *brinjal* in treatment $T_1$ was found to be the highest, thus gross benefit also was highest in treatment $T_1$ (Rs. 301490.00). Based on gross benefit and gross cost of cultivation, maximum benefit-cost ratio (3.86) was obtained in treatment $T_1$. Hence, it was concluded that in brunjal production, furrow irrigation with black plastic mulch results in the highest irrigation efficiency and highest net returns under the field conditions of the study area.

## थीसीस अमूर्त

| | |
|---|---|
| थीसीस का शीर्षक | बैगंन में विभिन्न मल्च का प्रयोग कर कुंड सिंचाई प्रणाली का मुल्यांकन |
| छात्रा का पूरा नाम | मनीषा लिल्हारे |
| प्रमुख विषय | मृदा एवं जल अभियांत्रिकीय |
| प्रमुख सलाहकार का नाम व पता | डा. ए. के. पाली (प्राध्यापक)<br>कृषि अभियांत्रिकीय संकाय, आई.जी.के.व्ही. रायपुर |
| डिग्री से सम्मानित किया जाता है। | कृषि अभियांत्रिकीय संकाय में मास्टर ऑफ टेक्नोलॉजी |

Mlilhare

छात्रा के हस्ताक्षर

Pal. 18/07/16

प्रमुख सलाहकार के हस्ताक्षर

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## अमूर्त

“बैगंन मे विभिन्न मल्च का प्रयोग कर कुंड सिंचाई प्रणाली का मूल्यांकन” नाम से कृषि अभियांत्रिकी संकाय, इंदिरा गांधी कृषि विश्वविद्यालय के प्रदर्शन प्रक्षेत्र पर अध्ययन किया गया। इस अध्ययन में पाँच उपचार शामिल थे जिनमे कुंड सिंचाई के साथ काली प्लास्टिक का पुआल ($T_1$), कुंड सिंचाई के साथ पैरा का पुआल ($T_2$), कुंड सिंचाई के साथ लकडी के बुरादे का पुआल ($T_3$), कुंड सिंचाई के साथ मृदा पुआल ($T_4$), एवं कुंड सिंचाई बिना पुआल ($T_5$) 2 लीटर प्रति सेकंड की जल धारा सभी पाँच उपचारो में सिंचाई के लिए इस्तेमाल किया गया। इस अध्यन में, बैंगन में विभिन्न पुआल के साथ कुंड सिंचाई के हाइड्रौलिक प्रवाह से संबधित प्रयोग किए गए। प्रत्येक उपचार में उत्पादन प्रणाली का आर्थिक विश्लेषण भी किया गया। इस अध्ययन से परिणाम प्राप्त हुआ कि कुंड सिंचाई प्रणाली लगभग 2 लीटर प्रति सेकंड की धारा के आकार के समांनातर थे। वक्र का समांनातर होना यह सुनिश्चित करता है कि पानी

का समान वितरण किया गया। पानी की निधार्रित गहराई 5.25 सेन्टी मीटर, अर्जित गहराई 6.99 सेन्टी मीटर एवं प्रत्येक सिंचाई में उपयोग की गई पानी की वास्तविक गहराई 6.85 सेन्टी मीटर पायी गई। हर उपचार में मृदा की मूल अंतः स्पंदन गति विविध रूप में 0.44,0.62,0.6,0.48 एवं 0.46 (प्रथम सिंचाई) 0.56, 0.62, 0.64, 0.54 एवं 0.52 (द्वितीय सिंचाई) 0.58, 0.6, 0.66, 0.52 एवं 0.5 (तृतीय सिंचाई). प्रथम, द्वितीय एवं तृतीय सिंचाई के बाद मिट्टी में नमी की मात्रा हर उपचार में, काली प्लास्टिक पुआल में अधिकतम एवं बिना पुआल में न्यूनतम पाया गया। उपचार $T_1$ में जल प्रयोग दक्षता साफ तौर पर अन्य उपचार की तुलना में बहुत अधिक रहा। बिना पुआल का कुंड सिंचाई प्रणाली $T_5$ में न्यूनतम जल प्रयोग दक्षता पायी गई। जल वितरण दक्षता $T_1$ में अधिकतम एवं $T_5$ में न्यूनतम पायी गाई। उपचार $T_1$ में काले प्लास्टिक पुआल की अपेक्षाकृत उच्च लागत के कारण खेती का कुल लागत अधिकतम रहा। बिना पुआल लागत के एवं कम श्रमिक लागत के कारण उपचार $T_5$ में खेती की लागत कम पायी गई। उपचार $T_1$ में बैंगन की अधिकतम पैदावार हुई जिससे लाभ भी इस उपचार में उच्चतम (301490.00 रु.) प्राप्त हुआ। उपचार $T_1$ में सकल लाभ व खेती की सकल लागत के आधर पर अधिकतम लाभ–लागत अनुपात (3.86) पाया गया। इस अध्ययन से यह निष्कर्ष निकाला गया कि बैंगन उत्पादन के लिए प्लास्टिक मल्च के साथ कुडं सिंचाई के कारण सिंचाई दक्षता एवं शुद्ध प्राप्ति अधिकतम प्राप्त की जा सकती हैं।

# CHAPTER - I

# INTRODUCTION

Water is a precious and most commonly used resource but the availability of fresh water is not unlimited. Due ever-increasing population rapid urbanization and industrialization, water availability for agriculture is shrinking day-by-day. Agriculture sector is a the major water consuming enterprise as the water is one of the limiting factor for agricultural production. Often crops suffer greatly due to insufficient water availability and improper scheduling of water application resulting in low yields. It is therefore essential to increase the water productivity of irrigation methods if food-grain availability to increasing population is to be ensured. Irrigation methods like sprinkler and drip systems are considered as the most water efficient methods. But they cannot be used for every crop and also they require large capital investment. The resource poor farmers cannot affort them. Hence, the surface irrigation methods are and will be used by most farmers. Although, surface irrigation is the most widely used it is considered as low water application efficiency, particularly in furrow irrigation system, in which the furrow is responsible for lower efficiency levels. Surface irrigation is an irrigation method where water drain by gravity, using the agricultural soil surface as part of the water distribution system (Lima et al., 2014). Surface irrigation continues being the most used irrigation system in the world even thought its efficiency range between 30% and 50% (Rosano-Méndez et al., 2001; Sió et al., 2002); nevertheless Hsiao et al. (2007) discussed some works (Erie & Dedrick, 1979; Howell 2002) which conclude that application efficiency can be higher than 80% if surface irrigation is practiced well under the right conditions.The low irrigation efficiency combined with the decreasing water availability for irrigation seems to be determental to agriculture but it also raiseds opportunity so that surface irrigated agriculture makes a more rational water use. Irrigators face intensive competition for limited water resources from other sectors of economic activity such as urbanization and industrialization. Therefore, irrigation system designers must strive to find the best design and management in order to maximize benefits and minimize water use. Improved efficiency in irrigation system design can help reduce the amount of irrigation water applied, thereby reducing water logging while at the same time maintaining crop water needs. Efforts in surface irrigation research and extension have focused on methods for providing better control and management of water in agriculture. When surface irrigation systems are properly designed, operated and managed, higher irrigation efficiencies and application uniformities can be achieved.

Furrow irrigation system finds an important place among the surface irrigation methods. It is the oldest, practical, and most common types of surface irrigation systems. It can afford high irrigation efficiency if properly designed operated and managed. The effectiveness of furrow irrigation can further be improved by using mulches at the ridges on which crop is planted. Mulching helps in increasing the moisture availability to the crop for longer period by reducing evaporation loss. Besides this, mulching suppresses the weed growth also, thereby increasing fertilizer use efficiency and decreasing cost of weeding. The primary objective for effectiveness of furrow irrigation is that how efficiently the system hydraulically perform and how much area can be irrigated per unit of water applied. The hydraulics of furrow irrigation has been studied by many researchers in the past. The results of those researches led to a better understanding of water flow problem on porous media, specifically the behavior of soil infiltration rate and water advance phenomena. Furrow irrigation system can be characterized according to how they function hydraulically and distinction can be made by advance and recession pattern of water front within the furrow, which describes the time when the advancing stream reaches particular locations and the time when standing water no longer occurs there. This hydraulic comparison assumes that water enters the field along one end and flows to the other end uniformly across the furrow width. The main distinction in hydraulic performance are thus related to the magnitude and pattern of the inflow rate, the general shape of the recession curves, the runoff hydrograph and system’s efficiency. With the rising demand for water and community aspirations to use water wisely, there is a need to use irrigation water in the most effective manner to get the best possible return on it. Furrow irrigation in combination with plastic mulch is a highly efficient water-saving irrigation technology. While the plastic film covers the ridge, it allows the plants to grow through holes and a certain gap is maintained in the furrow for irrigation. Because of its notable functions for saving water, increasing yield, reducing soil evaporation and preserving soil temperature, furrow irrigation with plastic mulch on ridge is remarkably improves water use efficiency. This technology is especially suitable for growing vegetables.

Brinjal or eggplant (*Solanum melongena* L.) is an important solanaceous crop of sub tropics. The name eggplant has been derived from the shape of the fruit of some varieties, which are white and resemble in shape to chicken eggs. It is also called aubergine (French word) in Europe. The brinjal is of much importance in the warm areas of Far East, being grown extensively in India, Bangladesh, Pakista. The name brinjal is popular in Indian subcontinent. In India, it is one of the most common, popular and principal vegetable crops grown throughout the country except higher altitudes. It is a versatile crop adapted to different agro-climatic regions and can be grown throughout the year. It is a perennial but grown commercially as an annual crop.

Studies have shown that brinjal crops perform very well with mulching and furrow irrigation. Mulches can either be organic such as grass clippings, straw, bark chips, and similar materials or inorganic such as stones, brick chips, and plastic. Both organic and inorganic mulches have numerous benefits. Though, the results in many places in India for furrow irrigation with mulching are very encouraging, very little studies have been conducted on this technology in Chhattisgarh.

In view of the above, the present study was conducted with the following specific objectives:

1. Hydraulic evaluation of furrow irrigation with different mulches in brinjal.
2. Performance evaluation under the above production system.
3. Economic analysis of the production system.

# CHAPTER-II
# REVIEW OF LITERATURE

A brief review pertaining to research work conducted on hydraulic parameters, furrow geometry, irrigation characteristics, advance and recession, irrigation efficiencies are in this chapter.

## 2.1 Design of Furrow Irrigation

Descriptions of the furrow cross section are required in many formulations that have been developed to model furrow irrigation performance. Researchers have presented techniques for measuring the furrow cross section in the field, and have described the effect of furrow cross-sectional shape on furrow irrigation performance. Methodology and techniques are available to analyze furrow cross-sectional data to arrive at some of the commonly used empirical descriptions of the furrow cross section. The furrow can have an assumed shape, triangular or parabolic, or the observed cross-section measurements can be used numerically. In most cases the observed cross-section data should be numerically integrated to develop a data set from which the desired empirical shape descriptions can be estimated.

Esfandiari et al. (1998) investigated the suitability of selected flow equations and variation of Manning's *n* in furrow irrigation. In this study they examined the suitability of the Manning and other four similar flow equations for flow in furrow and evaluated how Manning's *n* varies spatially, temporally and with flow rate in the furrow. Field tests were monitored for a range of flow rates and two furrow slopes. The Manning and the other equations fitted data satisfactorily. The value of the Manning's *n* varied slightly with the variation in flow range, but it became fairly constant with changes in flow rate at low flow range, but it became fairly constant with changes in flow rate at high flow range. The manning equation is considered the best for modeling the overland flow in furrow irrigation among the equations examined in the study because the manning equation requires only one parameter to be estimated, whereas in the other equations up to four parameters should be estimated.

John et al. (1999) evaluated explicit time of advance formula for furrow design. The behavior of the dimensionless advance curves were obtained numerically for various values of infiltration parameter. It was found that when the advance problem is expressed in terms of new variables conveniently selected, the various advance curves can be described by a single curve independent of infiltration parameter. A simple, explicit, time of advance formula that fits the single curve previously reported was derived. Comparison tests indicated that when an adjusted shape factor for the surface profile is used, the predictions of the proposed formula are in agreement with accurate kinematic wave numerical solutions. An optimal design procedure for furrow irrigation using the above formula was thus presented.

John et al. (2001) developed and used a simple equation of time of waterfront advance to calculate advance time surface irrigation. The proposed equation was be used for routine furrow irrigation design. The equation was derived as an extension of  small-time, large-time explicit solutions. Systematic comparisons of dimensionless solutions indicated that the prediction of the equation is in agreement with the accurate zero-inertia numerical solutions. The accuracy of the simple U.S. Soil Conservation Service explicit time of advance empirical equation was also evaluated. Comparisons have shown that the U.S. Soil Conservation Service equation performed generally poorly. The suggested equation was also compared with observed furrow data and with the accurate zero-inertia model. The provided predictions are in agreement with the numerical model and observed data.

John et al. (2001) developed a simple algebraic equation for a specified furrow length to directly calculate the appropriate inflow rate (and cutoff time) so that the minimum cost of the furrow system was obtained. The proposed equation was independent of the water and labour cost coefficients. Comparison tests indicated that the optimum inflow rate values obtained analytically were in close agreement to the optimum values obtained using the outcome of the zero-inertia numerical model. The method was extended for furrow design considering the furrow length also as a design variable. The optimum number of widthwise distribution lines and furrow sets were easily determined by a simple calculation procedure.

Dawit Zerihun et al. (2001) analysed the design of furrow irrigation systems based on the criterion of application efficiency. The application efficiency function was unimodal with respect to inlet flow rate and furrow length. Optimality conditions were also derived for the cases in which application efficiency was a function of both inlet flow rate and furrow length when application efficiency was expressed as a function of either furrow length or flow rate. Simple and sufficiently accurate equations and design and management rules were developed.

Okereke et al. (2005) determined the design inflow rate in furrow irrigation using simulated advance and recession curves. In this study, they simulated advance and recession curves for three stages of maize growth in furrow irrigation. The selected stages were: the emergence stage, two weeks after planting; the development stage, about two months after planting; and the maturing stage, about one month to harvest time. The advance and recession times were predicted for successive points along the furrow lines for various inflow rates at the development stage of the crop growth using three models. The simulated advance and recession data were used to compute the intake opportunity time distribution along the furrow line. The infiltrated depth distribution and hence the water application efficiency and distribution uniformity were computed for the inflow rate, which gave 87% and 89% for the maize emergence stage: 75% and 60% for the maize development stage and 95% and 89% for the maize maturing stage. The design inflow rate for each furrow was taken as the minimum inflow rate which gave rise to a minimum water application efficiency of 60% and a minimum distribution uniformity of 75%. It was recommended that the procedure described in his work is useful for the modification of existing furrow irrigation systems and the establishment of new ones. Also, the design procedure presented can be used for any field that is suitable for furrow irrigation system by making use of the relevant parameter estimates that can be obtained from the field.

Garg *et al.* (2006) investigated the furrow irrigation system for developing relationship of irrigation performance parameters with the design variables, crop yield and net income from maize crop. In the study, water application efficiency, water requirement efficiency, water distribution efficiency and requirement distributions efficiency were examined for the relationships with inflow rate, length of furrow and time of inflow. Requirement efficiency was found to be exponentially related to design variables of furrow geometry while the relations between water requirement efficiency and relative yield of maize crop as well as net income were of quadratic function. The water requirement efficiency and requirement distribution efficiency had good correlation with furrow design variables, relative yield and net income. However, water distribution efficiency correlated poorly with relative yield and net income. Water application efficiency was also found having very poor linear correlation with design variables.

Panigrahi (2008) developed crop coefficient model of potato under plant-furrow treatment. The models predicted potato crop coefficient and were compared with the FAO-24 reported crop coefficients. At lower irrigation level, the coefficients agreed well for initial and mid-season stage but differed at the maturity stage. The reverse trend was marked for higher irrigation level. The developed model can be used in estimation of daily crop coefficient which will help in computing the actual crop evapotranspiration demand for better irrigation scheduling on regional basis.

Kumar and Sahu (2013) conducted a study on comparison of furrow irrigation and drip irrigation systems to see the effect of different levels of irrigation and fertigation levels on the performance of Cabbage crop at Horticultural Research Farm of Indira Gandhi Krishi Vishwa Vidyalaya, Raipur during the year 2007-2008. They found higher plant height and number of leaves per plant in all irrigation levels and fertilizer levels in drip system as compared furrow irrigation method. Higher water use efficiency was also observed in drip irrigation method when compared with furrow irrigation method.

Khalkho *et al.* (2013) conducted a study on irrigation scheduling and effect of different soil moisture regimes over the yield and growth parameters of *rabi* chilli crop with furrow irrigation as one of the experimental treatments for effective irrigation water management in Bastar agro climatic zone. The study also aimed to determine the minimum irrigation to be given or supplied in order to achieve significant returns from the crop along with identification of simple guideline for determination of soil moisture status. Eight treatments of irrigation (T1 to T8) including that of seven different available soil moisture (ASM) levels at 70% (T1), 60% (T2), 50% (T3), 40% (T4), 30% (T5), 20% (T6) and 10% (T7) along with one treatment of furrow irrigation at different vegetative stages (T8) of chilli crop was tested. The results showed that irrigation at 60% ASM level gave the highest yield as 9.145 T ha$^{-1}$, whereas the highest water use efficiency (0.37 T ha-cm$^{-1}$) was found in both the treatments, T1and T2. Results also showed that there was a significant reduction in the yield of chilli in treatment T6 of irrigation at 20% ASM (7.015 T ha$^{-1}$). It was also found that chilli crop survived the moisture deficiency of 80% with substantial returns.

## 2.2 Hydraulic Performance of Furrow Irrigation system

Efficient water application in furrow irrigation depends on the knowledge of hydraulics of flow in furrows. The flow phenomenon in furrow irrigation is unsteady open channel flow with decreasing discharge. The discharge at a specific point changes with time due to independent intake behavior of soil. At the advancing end of water body, particularly depth also changes in time and space. Equation describing continuity of mass momentum and energy for this flow conditions have been developed and verified in many literature sources (Walker, et al., 1987).

Bautista et al. (1993) used optimal management strategies for cutback furrow irrigation. The optimal management of a cutback-furrow-irrigation system with spatially variable infiltration based on an average intake function was analyzed. The problem was formulated as a cost-minimization function subject to meeting a specified fraction of the irrigation requirement. Optimal solutions were examined in the context of developing a real-time control system for furrow irrigation. Although, total infiltration was adequately predicted with the average function, final water distribution was not. Consequently, the optimal policies resulted in actual requirement efficiencies less then the target value. Nonetheless, relative changes in performance as a function of the constraint were well predicted. The performance index was relatively insensitive near the optimum, and cutback time had the least impact on application efficiency and uniformity. Satisfactory performance was therefore still obtained by reducing the inflow after the final advance time. Similar values of application efficiency were generally computed with decreasing application depths, but smaller efficiency resulted when the optimized cutoff time was less then the final advance time. There were small performance differences between discrete and continuous-time cutback functions.

Alazba et al. (1999) simulated furrow irrigation with different inflow patterns. They considered sloping furrows with free outflow to assess the effect of inflow pattern on maximum application efficiency. For five inflow hydrograph patterns, the maximum application efficiency was predicted utilizing a zero inertia model, which describes the movement of water in the furrow with infiltration. `The irrigation parameters considered were four infiltration families, three slopes, three roughness coefficients, two field lengths, three volumes, and one furrow shape size. The maximum application efficiencies averaged over all combinations for the five inflow patterns were constant rate, 58%; cutback, 64%; cablegation, 51%; modified cutback, 64%; and modified cablegation, 62%. Efficiencies ranged from zero for each inflow shape to a magnitude that differs from one to another, with the low values occurring for high infiltration rates and roughness, small slopes, long fields, and low volumes of application. While the constant rate was found to be least sensitive to changes in the input parameters, cutback and modified cutback were most sensitive. Cablegation and modified cablegation were moderately sensitive to changes in the input parameters.

David et al. (2006) made a sensitivity analysis of soil hydraulic properties on subsurface water flow in furrows. Results showed that the first irrigation event was clearly more sensitive than the second one. The latter event was mainly associated with the nonuniformity of the initial soil water contents within the soil profile. Pressure heads in the soil profile were more sensitive than cumulative outlet fiuxes and soil water contents. Sensitivity analysis results for pressure heads, cumulative fluxes, and water contents indicated that in every case the most sensitive parameter was the hydraulic property shape factor (*n*) followed by the saturated water content (θs), the saturated hydraulic conductivity ($K_s$), the residual water content (θ/dr), and the shape factor in the soil water retention curve (α), with the pore-connectivity parameter (*l*) the least sensitive parameter during both irrigation events. Pressure head sensitivity analysis for all parameters studied showed that the least sensitivity was linked with the wetting front as it gradually moved deeper with time, and the highest sensitivity was observed in those regions where th initial soil water contents were lower. Similarly, for water contents, higher sensitivity occurred in the drier regions during the first irrigation event and near the moisture front in the second irrigation event. Both pressure heads and water contents showed some sensitivity near the soil surface during both irrigation events, suggesting the importance of evaporation from the soil surface.

Lazarovitch et al. (2009) applied moment analysis techniques to describe the spatial and temporal subsurface wetting patterns resulting from furrow infiltration and redistribution. The water added was considered as a “plume” with the zeroth moment representing the total volume of water applied to the domain. The first moments lead to the location of the center of the plume, and the second moments relate to the amount of spreading about the mean position. Using moments, any fraction of the applied water and its spatial extent, defined by an ellipse, can be related to a “probability” curve. Remarkably, the probability curves were, for practical purposes, identical for all times and for all of the soils considered in this study. The same observation was made in relation to the distribution of water under a dripper. The consistency of the probability relationships can be exploited to pinpoint the distribution of irrigation water under a furrow in a compact and physically meaningful way. This approach was tested with numerically generated data for infiltration from furrows in three contrasting soils. The general conclusion was that moment analysis allows a straightforward, physically meaningful description of the general pattern of moisture distribution. Potential applications of the results of moment analyses included improved irrigation management, formulation of the infiltration and redistribution process from a furrow in a neural network setting, and parameter estimation of the soil hydraulic properties.

Shiyan Zhang et al. (2012) developed a one-dimensional numerical model for the simulation of unsteady flow and the resultant soil erosion in irrigation furrows. The model solves a modified version of the Saint-Venant equations that consider the loss of mass and momentum attributable to infiltration and sediment transport. The transport rate of fine sediment was predicted with a modified Laursen formula that treats the tractive shear stress as a function of both Reynolds number and the particle size. The modified Laursen formula was verified by using the erosion data measured in the field and in a laboratory flume. The model accurately predicted flow advance times and outflow hydrographs in comparison with data measured in irrigation furrows at Kimberly, Idaho. Sediment discharge predictions were less accurate.

### 2.2.1 Furrow Geometry Parameters:

Furrow geometry parameters are required for evaluating furrow irrigation. Cross sectional area is required to evaluate surface storage and flow velocity. Flow depth is required to calculate water surface elevation and thus the friction slope in zero-inerita and hydrodynamic surface hydraulics model. Infiltration rate has been related to wetted perimeter. Hydraulic radius is needed to calculate tractive force for erosion models. Surface flow equation relates the geometric parameter to the hydraulic parameters.

Trout (1991) found that constant shape does not fit for measured furrow shapes and also the commonly used rigid perimeter model is not conceptually correct during recession. However it predicted the important relationship between flow area, depth and wetted parameter and the channel section factor nearly as well as the rigid perimeter model and its coefficients were easier to determine. With the constant shape model generalized relationship existed between hydraulic and geometric parameters, which gave insight into processes important to surface irrigation. The predictions of both models were found more sensitive to furrow top width ratio to flow depth ratio than to shape.

Thomas et al. (1991) conducted a study on furrow geometric parameters for modeling and evaluating furrow irrigation. Currently used shape models assume the furrow perimeter is rigid so that only the flow depth increases with capacity. Actual furrow perimeters are not rigid and may widen as their capacity increases. If the furrow width increases proportionally with flow depth, the flow cross-sectional shape remains constant and only the size increases with capacity. This constant-shape model results in simple generalized relationships between the hydraulic and geometric parameters, which simplifies analysis of the complicated interactions that occur during furrow irrigation. The two shape models were compared conceptually and against field measurements. The rigid parameter model better matched field-measured furrow shapes and is easier to rationalize conceptually. However, both models matched the important relationships between furrow geometric parameters and hydraulic parameters equally well. The most important relationship between flow area and uniform flow section factor was found insensitive to both the model and shape. The predictions of both models were more sensitive to the furrow top width-to-flow depth ratio than to shape.

Trout (1992) measured the steady-state effects of wetted perimeter and flow velocity on furrow infiltration. Three approaches were taken to quantify the individual effects. A recirculating infiltrometer was used to quantify the individual effects. A recirculating infiltrometer was used to apply a wide range of flow rates to furrows constructed on wide range of slope in order to statistically separate the effects of wetted perimeter and flow velocity. Secondly, the independent effect of wetted perimeter was measured in stagnant furrows. Thirdly, field scale infiltration measurements were made to verify the infiltrometer results. Stagnant blocked furrow measurement on silt loam soil supported the relationship between wetted perimeter and infiltration. However, both recirculation infiltrometer and field scale measurement showed no consistent infiltration wetted perimeter relationship. The infiltrometer data, collected using a wide range of flow rates on a wide range of slope, showed infiltration being inversely related to flow velocity. Because both velocity and wetted perimeter increase with flow rate, their opposing effect on infiltration can result in little apparent effect when flow rates change. These interactions strengthen the inverse relationship between infiltration and furrow slope.

Esfandiari and Maheshwari (1998) examined the suitability of Manning and other four similar flow equations for flow in furrow irrigation and evaluated that Manning’s ‘n’ varied spatially, temporally and with flow rate in the furrow. Field test were monitored for a range of flow rates and two furrow slopes. The value of Manning’s ‘n’ varied slightly with variations in flow rate at low flow range but it became fairly constant with change in flow rate at high flow range. The Manning equation was considered the best for modeling the over land flow in furrow irrigation among the equations examined in the study because Mannings equation required only one parameter to be estimated, whereas in other equations up to four parameters were estimated.

Strelkoff (2000) conducted a study approximating wetted perimeter in power-law cross section. The wetted perimeter is an open-channel parameter thst influences surface drag and also influences infiltration in furrows and unlined canals. Various approximations to the wetted perimeter were examined for channel cross sections in which the top width is a power law of depth. Exact solutions were available only for selected values of the exponent. Interpolation between exact values, partial sums of series approximations, and numerical integration were compared. A simple nonlinear interpolation scheme or a three-term summation yields resulted accurate to within 1% in the range of typical channel geometries. Common numerical approximations were shown to yield errors ranging from 3 to 10%.

### 2.2.2 Infiltration Characteristics

The movement of water from the surface into the soil is called infiltration. The infiltration characteristic of the soil is one of the dominant variables influencing irrigation. Infiltration rate is soil characteristic determining the maximum rate at which water can enter the soil under specific condition including the presence of excess water. The actual rate at which water is entering the soil at any time is termed as infiltration rate.

#### 2.2.2.1 Infiltration Simulation

Infiltration of water into the furrow is the most important variables affecting the characteristics of flow in furrows. The infiltration rates in furrows are determined by gravimetric method, furrow infiltrometers and inflow-outflow method. The inflow-outflow method is also known as volume balance method and considered to be most satisfactory one because it gives the average infiltration value by compensating various errors inherent in the furrow, soil heterogeneity, furrow cross section difference, cracks and puddling effect (Michael, 1982).

Elliottt and Walker (1982) calibrated modified Kostiakov Lewis parameters. They have made large number of point of measurement of infiltration rate using blocked furrow and cylinder infiltrometer. These data have never allowed a satisfactory simulation of actual furrow advance nor an accurate prediction of tail water volumes. It was found that most effective evaluation methodology is to measure advance rates, hydraulic cross section area and tail water volume. They used two point methods for calibrating parameters of modified Kostiakov Lewis infiltration equation. The values of basic infiltration rate were determined by blocked furrow test, volume balance approach, published value for type of soil and inflow-outflow method. The inflow-outflow method gave best estimate of basic infiltration rate followed by published value of infiltration rate based on soil type.

William et al. (1989) utilized infiltration function from furrow stream advance. They found that the average infiltration rates for large land areas can be quickly determined using a new procedure for obtaining the coefficients of the Kostiakov equation. By introducing the concept of average opportunity time it is possible to plot the infiltration function directly from tabulated data. This modification of the volume-balance method is a straightforward one, which is easy to understand and learn.

Wynn et al. (1990) estimated real-time of furrow infiltration and an analysis to determined infiltration parameters from the early stages of furrow advance is reported. The analysis used a kinematic-wave simulation model in conjunction with a simplex search procedure to minimize the differences between measured and predicted advance rates. The technique used a variable and expanding data set to forecast advance times and is therefore a useful prelude to real-time feedback control systems for the future automation of furrow irrigation systems. Results from four furrow evaluations involving a sandy loam and a silt clay loam were given to demonstrate the capability of the analysis. The analysis was first verified by using the complete advance data sets for the evaluations. The analysis yielded the same values of the three Kostiakov-Lewis infiltration parameters found in independent field measurement. In a second investigation, the basic intake-rate parameter in the Kostiakov-Lewis function was fixed and the analysis was repeated with advance data from the early stages of advance to determine if and how soon the analysis would estimate reasonably accurate values of the other two infiltration parameters. The results indicated that infiltration parameters can be estimated with sufficient accuracy from early advance data to allow an accurate forecast of efficiency and uniformity at the end of the irrigation.

Bautista et al. (1991) optimized furrow infiltration parameters from advance times and advance rates. He analyzed the potential for identifying average parameters by minimizing the sum of squared differences of measured and model predicted advance, a classical parameter identification problem. A hydrodynamic model simulated irrigation advance in which intake was assumed to vary with wetted perimeter. Computer simulated (with spatially variable infiltration) and field measured irrigation data were used to assess the reliability of results and convergence of the algorithm.

Leel et al. (1992) evaluated infiltration in furrow irrigation. They used the recession simulation further to establish the basic infiltration rate in a furrow and, therefore, the infiltration characteristics in a furrow. Determining infiltration in a furrow is complicated by the dynamic flow nature of irrigation water, as well as the geometric shape of the channel, among other factors. The evaluation of this infiltration in furrows is important in order to evaluate the water use in such irrigation systems. The use of the Kostiakov equation in its extended form was suggested for the determination of infiltration characteristics in a furrow. This equation, however, depends on the evaluation of the long-term basic infiltration rate, which can be determined practically by a long-term tedious inflow/outflow hydrograph of the irrigation event. An analytical method based on the kinematic wave theory and recession flow data was proposed here to evaluate the long-term basic infiltration rate pertinent to the correct evaluation of the infiltration flow characteristics in a furrow.

Shepard et al. (1992) conducted field experiment to test the one point method in San Joaquin Valley. Infiltration was measured with neutron probe, infiltrometer and volume balance method. They found that infiltration estimated from water diverted to the field was over predicated because of runoff which was not measured and not deducted. Infiltration measured with neutron probe, as the difference between water content before and after irrigation, was under estimated because drainage during irrigation was not measured. The standard to compare infiltrometer and volume balance was thus between neutron probe and water applied estimate. The one point method for estimating furrow infiltration was consistent with standard.

Bautista and Wallender (1993a, 1993b) developed a parameter identification model based on hydrodynamic model to compute furrow infiltration parameter from irrigation advance measurements. Parameters were computed by minimizing the squared difference of observed and predicted advance times to specify on the field or alternatively advance rate. The Marquarat algorithm was used to compute the optimal solution. Convergence of the model was examined using simulated and measured irrigation. The identification model consistently failed to converge when fitting all three parameters of the extended Kostiakov infiltration using field data, but excellent results were obtained when fitting only two parameter (K and $\alpha$ or K and c) of equation ($Z = Kt^2 + ct$).

Edmar et al. (1995) used a volume balance approach to determine the parameters of the Kostiakov or modified Kostiakov infiltration equation in border and furrow irrigation. They used information from the advance phase only, wetting phase only and from both advance and wetting phases the results revealed that infiltration equation parameters obtained from advance phase and from the advance and wetting phase combined considerably improved and provided more accurate estimates of infiltrated volume.

Esfandiari and Maheshwari (1997) conducted field experiment at Walia Park at Quirindi located 350 km north of Sydney. The three methods selected for estimating infiltration characteristics in furrow irrigation were: optimization method, one point method and two point method. They found that modified optimization method was most accurate. Furthermore, the two point method failed to estimate the infiltration parameter in three out of 13 irrigation events

Jaun et al. (1998) developed a two dimensional infiltration model that incorporate the effect of surface sealing, soil cracking and initial soil water content. The model was compared with a finite difference solution of the Richard equation for vertical infiltration for two surface seal conditions. To further test the model, simulated data were compared with field experiments. Including infiltration through cracks provided a better agreement between observed and simulated data than when cracks were ignored; simulation showed that majority of the infiltration through cracks took place during the first few minutes of infiltration.

Upadhyaya and Raghuwanshi (1999) developed a semi empirical equation for cumulative infiltration in furrow irrigation system using an empirical wetting front advance equation and a volume balance technique. They conducted field test in clay loam soil planted with a furrow irrigated processing tomato crop at the agricultural field station at the University of California. The distinct cases onsidered were furrows with crust at the bottom (uncultivated) and the furrows in which a crust breaking device was used to remove the crust (cultivated). The semi empirical equation for cumulative infiltration correlated the measured cumulative infiltration very well for the calibration and prediction of data. The coefficient of multiple determinations was 0.997 for cultivated furrow and 0.998 for the uncultivated furrow.

Shrini et al. (1999) developed semiempirical infiltration equation for furrow irrigation systems for cumulative infiltration in a furrow irrigation system using an empirical wetting front advance equation and a volume balance technique.

This equation was verified by using the field data obtained in a clay loam soil planted with a furrow irrigated tomato crop. Two distinct cases were considered: (1) furrows with deposional crusts at the bottom (uncultivated); and (2) furrows in which a crust breaking device was used to remove the deposional crust (cultivated). The semiempirical equation for cumulative infiltration correlated to the measured cumulative infiltration very well for both the calibration and the prediction data set. Simulation studies were conducted to determine the possible use of this equation in furrow irrigation management.

Valiantzas et al. (2001) determined two intake parameters of Soil Conservation Service (SCS) infiltration equation. The time of advance at only one location of field, inflow rate and average flow area field data were used to estimate the two parameters of infiltration equation. Estimates of infiltration by one point method were compared wirh measured furrow infiltration data. It was found that proposed one point method gave more accurate results than previous one-point method.

Boroumandnasab et al. (2001) evaluated soil infiltration in furrow irrigation and determined the Kostiakov and Kostiakov-Lewis equations coefficients. Results indicated that correlation coefficient in the first irrigation period is low in comparison with the others periods. Cumulative infiltration was reduced in the second irrigation in comparison with the first irrigation 180 minutes after irrigation started. Also cumulative infiltration was reduced in the third irrigation in comparison with the second irrigation. During the fourth irrigation, cumulative infiltration increased in comparison with the third irrigation which was due to the weed growth in thefurrows. Results showed that calculated infiltration rate using inflow-outflow method is 4.4 times greater than double ring method. The results also showed that for short time periods (less that 180 minutes), Kostiakov method is in a better agreement with Kostiakov-lewis method. Cumulative infiltration was shown to be higher using Kostiakov-lewis method in comparison to actual measurement for long time periods (more than 180 minutes).

Oyonarte et al. (2002) determined infiltration variability in furrow irrigation. In this study  they considered of different sources of Variability to irrigation water depth variability was quantified using a combination of variance techniques. This method was applied using field measurements from irrigation events performed on a loamy soil with a low-infiltration rate. Infiltration variability was estimated with blocked furrow infiltrometers. The assumptions made for the application of the combination of variance techniques proved to be valid. The major variability source turned out to be the soil intake characteristics, whose variance accounted for 45-71% of the variance in infiltrated depth under first irrigation conditions. Opportunity time and wetted perimeter were less variable in subsequent irrigations and the soil intake characteristics variability accounted for a percentage of total variance beyond 76%, being at times beyond95%. The combination of variance techniques can be used to complement standard evaluation methods in order to take into account the influence of different variability sources.

Jean-Claude Mailhol (2003) validated a predictive form of Horton infiltration equation for simulating furrow irrigation. He used Horton's equation, derived from the asymptotic form of the Talsma-Parlange infiltration equation which allows to use a predictive approach for the advance infiltration process by means of the exact solution of the Lewis and Milne water balance equation. For a surface point source the analysis resulted in the use of parameters which characterize the hydraulic properties of the soil: Δθ (saturated water content minus initial water content); Ks (saturated conductivity); and λc (macroscopic capillary length). The physical meaning of parameters involved in the proposed modeling was attested using field experiment carried out in a loamy soil. Assuming a same Δθ measured value before irrigation for the whole of a 30 furrow sample, the averaged values of λc and Ks obtained from calibration on the advance trajectory were found comparable to those derived from local infiltration tests (disk permeameter and double ring methods). The applicability of the model was then extended to heavy clay soil where the parameters λc and Ks still agreed with the values proposed in the literature. This study can be considered as a contribution to the development of a tool for evaluating the impact of irrigation practices on the efficiency at the plot and cropping season scale.

Holzapfel et al., (2004) determined infiltration constant of Kostiakove equation using two point method, furrow infiltrometer method, advance method and one point method for two furrow sizes having top width 40 and 60 cm. based on representative data of central valley Chillan, Chille, It was found that values of infiltration constants depended on the methodology employed in the measurement. For a wide furrow, the two-point method showed the better performance to one point and two point method in determining the Kostiakov constant.

Damodhara et al. (2008) developed quick method for estimating furrow infiltration simple and quick method for estimating furrow infiltration was proposed using a single advance point based on the volume balance equation. The furrow infiltration and water front advance along the furrow were assumed to follow the modified Kostiakov infiltration and power advance equations, respectively. The volume balance equation, including these equations, was simplified to a function containing two parameters, i.e., the exponents of power advance and Kostiakov infiltration equation (with a prior-known basic infiltration rate). These parameters were estimated by minimizing the function to zero using a quasi-Newton search algorithm, provided with Excel Solver. The estimated exponents were used to determine the Kostiakov infiltration parameters. The proposed one-point method was tested with seven independent furrow irrigation evaluation data sets and the estimated cumulative infiltration was compared with the observed counterparts. Performance of the proposed method was evaluated using the root-mean-square error (RMSE) and index of agreement ($I_a$). The results showed that the proposed one-point method estimated cumulative infiltration closer to the observed; the method performed as good as Valiantzas' method. Shepard's method did not perform well for the tested data sets. The algorithm and the results of the proposed method revealed that the proposed method can be used as a tool for quick estimation of furrow infiltration using a single advance point.

Ahaneku (2011) used infiltration characteristics of two major agricultural soils in North Central Nigeria. This study was undertaken to assess the infiltration characteristics of two major agricultural soils in North Central Nigeria with a view to suggesting management strategies to improve infiltrability. The double ring infiltrometer was used for the infiltration measurements, while bulk and core samples of the soils were analyzed for their physical properties. A total of two infiltration runs were carried out for each soil type. Results indicated that maximum cumulative infiltration of 122 mm was observed for sandy loam soil after 4 hours, while that for sandy clay loam soil it was 27.8mm after 11/2 hours. Steady state infiltration rate of 30 mm/hr and 3 mm/hr were observed for sandy loam and sandy clay loam soils after 3hours and 11/2 hours, respectively. The saturated hydraulic conductivity (Ks) measured on soil cores showed that sandy loam had a higher value than sandy clay loam. The observed trends could be attributable to the physical properties of the two soils as a result of their textural differences, and have implications for irrigation scheduling and flood control.

Rahimi et al. (2011) evaluated soil infiltration in furrow irrigation. The purpose of this study was to compare infiltration measurement results, using double ring and inflow-outflow method following consecutive irrigation events. Study of bulk density variation after each irrigation was another aim of this investigation. Experiments were conducted on a site near Agriculture Faculty of Shaheed Chamran University in Ahwaz. Results indicated that correlation coefficient in the first irrigation period was low in comparison with the others periods. Cumulative infiltration was reduced in the second irrigation in comparison with the first irrigation 180 minutes after irrigation started. Cumulative infiltration was also reduced in the third irrigation in comparison with the second irrigation. During the fourth irrigation, cumulative infiltration increased in comparison with the third irrigation which was due to weed growth in the furrows. Results show that calculated basic infiltration rate using inflow-outflow method is 4.4 times greater than double ring method. Results also showed that for short time periods (less than 180 minutes), Kostiakov method is in a better agreement with Kostiakov-Lewis method. Cumulative infiltration was shown to be higher using kostiakov-lewis method in comparison to actual measurement for long time periods (more than 180 minutes).

Baustista et al. (2014) found new results for an approximate method for calculating two- dimensional furrow infiltration. This studied expanded the analysis of a proposed furrow irrigation formulation based on an approximate solution to the Two- dimensional Richards equation. The approach calculates two-dimensional infiltration flux as the sum of one-dimensional infiltration and a second term labeled the *edge effects*. The edge effects vary linearly with time when the applied water pressure is constant. It is function of sorptivity, soil water content, and the empirical parameters $\gamma$ and $W_*$ that require calibration for the specific soil and furrow geometry. The primary objectives of the analysis were to better understand how furrow geometry affects the edge effect and the resulting empirical parameter values and to provide additional guidance for calibration. For a given flow depth, furrow geometry defines the wetted perimeter and the water pressure applied along that wetted perimeter. A sub objective was to evaluate the effect of the assumed soil water retention model on the calibration results. The results showed that the range of variation of $\gamma$ depends on the pressure value used for one-dimensional infiltration and edge effect calculations. This range can be reduced by using the wetted perimeter averaged flow depth $h_{avg}$, instead of the centroid depth, $h_c$, as in the original formulation. The use of $h_{avg}$ also eliminates the need to calibrate $W_*$, which is simply equal to the furrow wetted. For the range of soils and geometry examined, $\gamma$ varied in the range of 0.6-1.0, but the range was narrower with soils described with Brooks-Corey soil hydraulic models than with soils described with the Van Genuchten model (VG model). This was explained by the larger values of wetting front suction associated with water retention data fitted to the Brooks-Corey model. With careful calibration, the approximate infiltration model can produce results of high accuracy in relation to the Richards equation solution. Calibration is especially needed with heavier soils for which the contribution of the edge effect relative to total infiltration is substantial.

### 2.3 Mulching in Furrow Irrigation

Ramalan et al. (2000) studied the effects of furrow irrigation methods, mulching and soil water suction on the growth, yield and water use efficiency of tomato in the Nigerian savanna. They conducted a field experiment with tomato during the dry season on a clay loam soil to evaluate; three furrow irrigation methods (conventional furrow, conventional furrow with cut-back, and alternate furrow); two mulch treatments (with straw mulch and without mulch); and three irrigation schedules (5-day interval, irrigation at 30 and 60 kPa soil moisture suction). Days to 50% flowering and fruiting of tomato were unaffected by furrow irrigation methods. Mulch and irrigation treatments affected the growth of tomato. Paddy straw mulch applied in furrows delayed the attainment of 50% fruiting by 6 days. Fruit sizes at the ages of 17, 19 and 21 weeks after planting, marketable fruit yield, crop water use and water use efficiency were affected by all the 3 factors. Fruit weight was affected only by soil water suction. The interaction of furrow irrigation method, mulch and soil water suction affected crop water use efficiency. With respect to water use efficiency, alternate furrow irrigation was statistically at par with the conventional furrow method when the plots were mulched and irrigated at 5-day intervals.

Awodoyin et al. (2007) investigated the effects of three mulch types on the growth and yield of Tomato and weed suppression in Ibadan, Rainforest-savanna Transi-tion Zone of Nigeria. Field experiments was conducted in the 1998 and 2004 cropping seasons to assess the impacts of different mulching materials on weed control, soil temperature, soil moisture depletion and performance of tomato. The crop growth and fruit yield were studied under plastic (grey-on-black), woodchip (Teak) and grass (*Pennisetum*) mulches, with handweeded and un-weeded as controls in a randomized complete block design with three replicates. They also assessed weed dry matter and species spectrum, soil temperatures at 5-cm and 15-cm depths, and soil moisture depletion. Compared to unweeded control that had the least total fruit yield (2.7 t/ha in 1998 and 4.2 t/ha in 2004), mulch types and handweeded treatments increased the fruit yield by 152-237% in 1998 and 188-202% in 2004. Compared to mean pooled fruit yield from all mulched plots, unweeded treatment reduced tomato fruit yield by about 65% and 66% in 1998 and 2004, respectively. The weed control efficiencies of the mulches ranged between 91% and 100%. Dicotyledon weed species dominated the plots in the two years accounting for 81.8% in 1998 and 90% in 2004. The number of low-growing weed species enumerated on the plots was 11 in 1998 and 18 in 2004. After four weeks of no rainfall in 1998, moisture loss was least (1.68±0.10%) under plastic mulch and highest (13.96±0.08%) on the unweeded plot. The differences between morning and afternoon soil temperatures at 5 cm depth were low under grass mulch, woodchip mulch and unweeded control (5.0-5$^0$C) but high under plastic mulch and handweeded control (8.7-8$^0$C). Mulches are effective in weed control and conservation of soil moisture, and the plant-based mulches are most effective in reducing soil temperature. These improvements of crop growing environment resulted in increased tomato growth and fruit yield.

Mahmood et al. (2011) studied the effect of mulching on vegetables production in tunnel farming. The study was conducted to compare the productivity of cucumber and bitter-gourd under mulch and non-mulch conditions in tunnel farming. Two treatments were made i.e. furrow irrigation along with bed mulching (T1) and furrow irrigation without bed mulching (T2). Beds of 60 cm and furrows of 30 cm were made in six tunnels measuring 4 × 68 m. Nobel variety of cucumber was grown in three tunnels and floragin variety of bitter gourd was grown in the remaining three tunnels. The row to row and plant to plant distance was maintained at 50 cm and 25 cm, respectively for both the crops. Equal dose of recommended fertilizer and similar cultural practices were given to all the plants. Results showed that the average cucumber and bitter-gourd production in mulch conditions were significantly higher than non mulch conditions. There was 39.33% and 23.7% increased in production of cucumber and bitter-gourd, respectively due to bed mulching practice. It was concluded that the bed mulching practice was very useful to control the weeds and conserve soil moisture contents that in turn enhanced the plant growth.

Li-Min Zhou et al. (2011) conducted a study on ridge-furrow and plastic-mulching tillage with maiz crop. The results showed that film mulching enhanced soil microbial biomass; where microbial biomass carbon (MBC) in the DRM treatment reached 633 mg kg-1 at harvest in 2007, three times the MBC of the CK. The MBC:SOC ratios were 8.8%, 7.1%, 5.7% and 5.4% in DRM, RM, NM and WM, respectively. The ridge furrow with plastic-mulching increased soil light fraction carbon (LFOC) in both years, averaging up to 1.04 g kg-1 at harvest. Underground plant biomass increased substantially in the mulching treatments, especially in DRM. Positive correlations were found between total biomass and LFOC, between MBC and LFOC, and between MBC and available phosphorus (AP), but a negative correlation between SOC and soil mineral nitrogen (MN). The carbon to phosphorus (C/P) ratio was highest in DRM among treatments, but the content of SOC, MN, and C/N ratio in DRM was lowest, suggesting that the DRM treatment strengthened the interactions between maize and soil, and that the increased content of LFOC with time provides a basis for increasing productivity in future years.

Qin et al. (2013) studied the effect of ridge–furrow and plastic-mulching planting patterns on yield formation and water movement in potato crop in a semi-arid area. Field experiment was conducted to study the effects of different ridge–furrow plastic-mulching planting patterns (RFM) on potato growth, tuber yield and quality, and water use efficiency (WUE) in an arid area of Northwestern China in 2010 and 2011. Six treatments were used: (1) a flat plot without mulch (CK); (2) alternating mulched with plastic film and bare plots with no ridges (MNR); (3) completely mulched alternating wide and narrow ridges with furrow planting (CF); (4) completely mulched alternating wide and narrow ridges with ridge planting (CR); (5) alternating mulched ridges and bare plots with no ridges and with furrow planting (HF); (6) alternating mulched ridges and bare plots with no ridges and with ridge planting (HR). RFM systems greatly improved tuber yield and WUE of potato in comparsion to CK. Compared to CK, the magnitude of yield in RFM increase were 50.1–86.8% in 2010 and 36.3–60.5% in 2011, respectively. Two completely mulched treatments (CF, CR) produced the highest tuber yield. Compared to CK, the highest increase in WUE was 83.9% (CR) and 65.8% (CF) in 2010 and 2011, respectively. Evapotranspiration in RFM was significantly decreased compared to CK during the early and end growing stages. But ET in CF, CR, HF and HR became higher at vigorous growth stages (from 6 July to 27 August) due to higher transpiration, which may imply a higher ratio of transpiration/evaporation. CF and CR treatments resulted in higher dry matter and relative growth rate than other treatments, and had higher output efficiency of dry matter from aboveground to tuber. Potato in CR showed the highest tuber yield, output value, net revenue and WUE, produced tubers with good size, low percentages of green and blemished tubers, and high protein content. In conclusion, CR is the best planting pattern for rain-fed potato.

## 2.4 Economics of Furrow Irrigation with Mulches.

Prevatt et al. (1981) conducted an economic evaluation of three irrigation Systems for tomato production. Three hypothetical irrigation systems, seepage (modified furrow), subsurface drain, and trickle, were evaluated for soils with naturally high water tables to determine comparative irrigation costs for tomato production. Variable (operating) and fixed (ownership) costs were estimated for each irrigation system. The investment costs of the subsurface drain and trickle systems were significantly larger than the capital requirements for the seepage irrigation system. The variable costs, however, for subsurface drain and trickle systems were less than the seepage system due to the lower volume of water used by these systems. The seepage irrigation system was determined to be the most economical tomato irrigation system under present conditions.

Waterer (2000) investigated the effect of soil mulches and herbicides on production economics of warm season vegetable crops in a cool climate. The efficacy and cost efficiency of using various plastic soil mulches in the production of pepper, corn and muskmelon were examined over four growing seasons in Saskatchewan, Canada. Clear mulch with or without preemergent herbicides was compared with black or wavelength selective mulches. In all three crops, mulches enhanced yields relative to bare ground in most site–year combinations. Clear mulch usually produced the highest yields. Herbicides applied under the clear plastic provided effective weed control with no observable changes in product efficacy or toxicity to the crop. The weed control provided by the herbicides had no effect on yields in the clear mulch treatments. Consequently, clear mulch without added herbicide usually represented the most cost-effective production option for all three crops.

Oosthuizen et al. (2005) conducted a study on cost-estimating procedures for drip-, micro- and furrow-irrigation systems. The total annual fixed and operating costs of a drip-, micro- and furrow-irrigation system were estimated, as well as the marginal factor cost of water applied. An existing centre-pivot irrigation cost-estimating procedure was used. The type of irrigation system data needed were specified. The assumptions about the salvage value and expected lifespan of the system components are given. The total investment cost of the drip, micro and furrow-irrigation system was R200 000, R277 586 and R132 012 respectively. The total annual fixed and operating costs of the drip, micro and furrow-irrigation system are R28 509, R39 817 and R17 763 (fixed) and R36 957, R38 980 and R106 375 (operating) respectively. The marginal factor cost of water applied for the drip, micro and furrow-irrigation systems was R2.00/mm·ha, R1.90/mm·ha and R2.20/mm·ha. The proper estimation of irrigation costs is critical for irrigators to be able to evaluate efficient water use techniques.

Nelson et al. (2011) studied the agronomic and economic evaluated of various furrow irrigation strategies for corn production under limited water supply. It was commonly known that furrow irrigation was a less efficient method of irrigation than a sprinkler center pivot system, but many fields' irregular shapes prevent the use of center pivot irrigation. Restricted water allocations of surface and subsurface water are forcing farmers to implement irrigation strategies that will reduce water application on furrow-irrigated fields. The study site was located in south central Nebraska. The objective of this study was to evaluate two irrigation scheduling scenarios: (1) the every-furrow irrigation method with 50% (0.5), 70% (0.7), and 90% (0.9) field capacity (FC) treatments and (2) the every-furrow (EF) irrigation method compared to the every-other-furrow (EOF) method with both using the 75% field capacity (0.75 FC) treatment effects on corn yield, net economic return, and residual soil nitrate-nitrogen. The experimental design was a randomized complete block with three replications. Grain yield showed no significant difference in both years for all irrigation treatments. Irrigation water application with the 0.5 FC strategy reduced the amount of applied water by approximately 70% and 200% compared to 0.7 FC and 0.9 FC, respectively, in both years. The water savings with the EOF method over the EF method was 23%. The economic return with 0.5 FC was 6% to 13% and 36% to 69% over 0.7 and 0.9 FC irrigation treatments, respectively. The 0.5 FC strategy showed no significant reduction in nitrate-nitrogen loss over 0.7 FC and 0.9 FC, while the EOF method reduced soil nitrate-nitrogen loss by 11% to 26% over the EF irrigation method in both years. The average economic return over two years with the 0.5 FC strategy was 9.5% and 52.5% over 0.7 FC and 0.9 FC irrigation treatments, respectively, while the average economic return with the EOF method over the EF method was 9.5%. Findings demonstrated that economic and environmental benefits of using 0.5 FC or the EOF method was much superior to other furrow irrigation strategies, especially in areas with limited water resources where less efficient irrigation methods may lead to significant water loss.

Steve Amosson et al. (2012) conducted a study on economics of irrigation systems. The study found that the furrow irrigation requires less capital investment but has lower water application efficiency and was more labor intensive than the other irrigation systems. Compared to furrow irrigation, center pivots offer more than enough benefits in application efficiency and reduction in field operations to offset the additional costs. Advanced irrigation technologies were best suited to crops with high water needs, particularly in areas with deep pumping lifts. Producers using advanced systems will have not only lower pumping costs, but also potential savings from chemigation and the need for fewer field operations. Compared to LEPA center pivot, subsurface drip irrigation (SDI) was not economically feasible for any crop water-use scenario because of its relatively high investment and small gain in application efficiency. For most crops, adoption of subsurface drip irrigation may be limited to land where pivots cannot physically be installed. However, producers should closely evaluate using SDI systems for high-value crops. Research suggests that subsurface drip irrigation systems may improve the application efficiency and the timing of frequent applications. These improvements may increase acreage and yields enough to justify the additional investment costs of subsurface drip systems. Researchers also studied the effect on pumping cost of variations in fuel prices, pumping lift, amount of water pumped and labor wage rate. Results indicated that the less efficient the irrigation system, the more effect that fuel price, pumping lift and wage rate have on the cost of producing an irrigated crop. Therefore, when there was inflation or volatility of these cost factors, it was more feasible to adopt more efficient irrigation systems and technology. As more water was pumped, the fixed cost per acre-inch drops. Therefore, pumping more water encourages farmers to recapture their irrigation system investment more quickly.

Awad Abd El-Halim (2013) evaluated the impact of alternate furrow irrigation with different irrigation intervals on yield, water use efficiency, and economic return of corn. Alternate furrow irrigation with proper irrigation intervals could save irrigation water and result in high grain yield with low irrigation costs in arid areas. Two field experiments were conducted in the Middle Nile Delta area of Egypt during the 2010 and 2011 seasons to investigate the impact of alternate furrow irrigation with 7-d (AFI7) and 14-d intervals (AFI14) on yield, crop water use efficiency, irrigation water productivity, and economic return of corn (*Zea mays* L.) as compared with every-furrow irrigation (EFI, conventional method with 14-d interval). Results indicated that grain yield increased under the AFI7 treatment, whereas it tended to decrease under AFI14 as compared with EFI. Irrigation water saving in the AFI7 and AFI14 treatments was approximately 7% and 17%, respectively, as compared to the EFI treatment. The AFI14 and AFI7 treatments improved both crop water use efficiency and irrigation water productivity as compared with EFI. Results also indicated that the AFI7 treatment did not only increase grain yield, but also increased the benefit-cost ratio, net return, and irrigation water saving. Therefore, if low cost water is available and excess water delivery to the field does not require any additional expense, then the AFI7 treatment will essentially be the best choice under the study area conditions.

# CHAPTER-III
# MATERIALS AND METHODS

The present study was carried out on performance of evaluation of furrow irrigation system in Brinjal crop with different mulches at demonstration field of Faculty of Agricultural Engineering, IGKV, Raipur. This chapter discusses the experimental techniques, methodology used and different criteria adopted for evaluation of furrow irrigation, observations recorded on hydraulics of furrow irrigation under different mulching materials and crop response to furrow irrigation and economic analysis of furrow irrigated brinjal with different types of mulches. The details are discussed in the following sections.

## 3.1 The Study Area

### 3.1.1 Physiography

The demonstration field of Faculty of Agricultural Engineering, where the present study was conducted is situated at a distance of about 10 km from Raipur city at National Highway No. 6 which is known as Great Eastern road originating from Mumbai and connecting Kolkata. The geographic location of the study area is 21°14’9” N latitude and 81°42’10” E longitude with an altitude of 302 m above mean sea level. The experiment site is represented by Chhattisgarh plains agro-climatic zone. Total area of the experimental field measures 1023.75 $m^2$ with a length of 35 m and width of 29.25 m. The cross slope is 0.3 per cent in west to east direction and longitudinal slope is 0.6 per cent in south to north direction.

### 3.1.2 Climate

The climate of the study area is sub-humid. The main source of rainfall is South-West monsoon. Monsoon generally onsets by 15 June and starts withdrawing from 15 September. The pattern of rainfall, particularly during June to September months shows a great variation from year to year. The average annual rainfall of the study area is about 1300-1400 mm, of which about 80-85 per cent is received during third week of June to mid September and very little during October to February which is caused by south-east monsoon. In summer, May is the hottest month when maximum temperature goes as high as $45^0$ C in second fortnight of observed as May. December is the coolest month as temperature usually drops down up to 6° C. The historical weather records of the IGKV observatory shows that the maximum temperature generally varies between 23.5 °C and 46 °C during January to May, whereas the minimum temperature varies between 6.2 °C and 31 °C. Maximum rainfall during the period of experiment was 0.31 mm. Relative humidity through the year varied between 8.3 to 94.3 percent. The maximum relative humidity is experienced in rainy months and the minimum in summer season. The average value of pan evaporation ranged from 2.52 to 8.75 mm day$^{-1}$. The maximum average pan evaporation was observed as 10.3 mm day$^{-1}$ and minimum as 0.1 mm day$^{-1}$. The average sunshine hours was worked out as 7.64 hours day$^{-1}$. The maximum sunshine hours as 10.3 hours day$^{-1}$ were observed in summer season and the minimum as 0.1 hour day$^{-1}$ in monsoon season. Maximum wind velocity of 6.6 km hr$^{-1}$ and the minimum wind velocity of 1.5 km hr$^{-1}$ were recorded during the experiment period from January to April.

### 3.1.3 Physico-chemical characteristics of the soil

Soils of Raipur district show a large aerial variation. The red coloured residual soils are derived from the lateralization of shale and sand stones and the area covered by such type of soil is locally known as '*Bhata'* (*Entisol*) which are found at the upper part of the top-sequence. Next to the *Bhata* soils, there come '*Matasi*' (*inceptisol*) soils in the top-sequence which are pale yellow sandy loamy soils. After *Matasi* soils, light textured soils locally called '*Dorsa' (alfisol)* are encountered. The black coloured soils locally known as '*Kanhar*' (*vertisol*) are situated at the lowermost part of the topo-sequence as for as soil of the experimental plot is concerned it belongs to '*Dorsa' (alfisol*) which is texturally, classified as clay loam. The various physical and chemical characteristics of the soil of experimental plot are given in table 3.2.

Table 3.1 Weekly meteorological observations recorded during the year 2014-15

| Week | Month | Max Temp (${}^{0}$C) | Min Temp (${}^{0}$C) | RH I | RH II | Wind speed (kmph) | EP (mm) | Sunshine (Hour) | Rainfall (mm) |
|---|---|---|---|---|---|---|---|---|---|
| 03 | JAN | 26.05 | 08.28 | 90.71 | 30.57 | 2.01 | 2.75 | 8.54 | 0.00 |
| 04 | | 27.04 | 10.65 | 86.71 | 31.71 | 2.25 | 2.88 | 8.02 | 0.00 |
| 05 | | 28.10 | 13.11 | 89.57 | 36.42 | 2.60 | 3.40 | 6.64 | 0.00 |
| 06 | | 30.52 | 12.44 | 86.00 | 29.14 | 1.97 | 3.32 | 7.48 | 0.00 |
| 07 | FEB | 27.61 | 14.25 | 88.28 | 46.00 | 3.38 | 3.2 | 6.72 | 0.31 |
| 08 | | 32.74 | 14.80 | 84.57 | 29.00 | 2.95 | 4.54 | 9.82 | 0.00 |
| 9 | | 33.95 | 17.64 | 79.00 | 33.71 | 3.50 | 4.91 | 9.80 | 0.00 |
| 10 | | 28.64 | 16.30 | 87.42 | 44.14 | 3.54 | 3.74 | 6.74 | 2.74 |
| 11 | MAR | 33.80 | 18.88 | 76.85 | 33.71 | 3.54 | 5.22 | 7.40 | 0.00 |
| 12 | | 33.68 | 19.12 | 70.57 | 29.28 | 3.88 | 5.90 | 7.87 | 0.01 |
| 13 | | 38.08 | 21.10 | 62.14 | 22.42 | 3.50 | 7.74 | 8.81 | 0.00 |
| 14 | APR | 37.50 | 21.74 | 66.42 | 31.00 | 6.61 | 8.75 | 7.10 | 0.00 |
| 15 | | 37.05 | 22.54 | 75.85 | 40.85 | 6.50 | 7.98 | 7.02 | 1.48 |

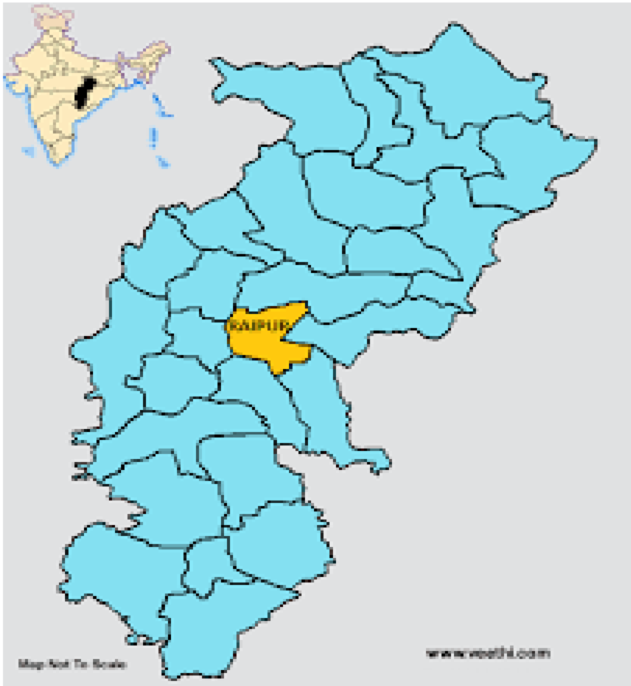


Fig. 3.1: Location map of the study area (Chhattisgarh State)

Table 3.2 Physicochemical characteristics of the soil of experimental plot

| **Particulars** | **Values** | **Rating** | **Method used** |
|---|---|---|---|
| **A.Physical properties** | | | International pipette method (Black, 1995) |
| 1.Mechanical composition | | | |
| Sand (%) | 19.05 | | |
| Silt(%) | 56.60 | | |
| Clay(%) | 44.80 | | Pressure plate apparatus method (Black, 1965) |
| Texture class | | Clay loam *(Alfisols)* | |
| 2.Field capacity (%) | 28.6 | | Pressure plate apparatus method (Black, 1965) |
| 3.Permanent wilting Point (cm/m) | 11.74 | | |
| 4. Water holding capacity (cm/m) | 18.24 | | |
| 5.Bulk density | 1.44 | | Soil core method |
| **B. Chemical composition** | | | |
| 1. Organic carbon (%) | 0.27 | | Walkley and Black's rapid titration method (Jackson, 1967) |
| 2.Available N (kg/ha) | 179.616 | | Alkaline permagnate method (Subbiah and Asija 1956) |
| 3. Available P(kg/ha) | 9.89 | | Olsen's method (Olsen's 1954) |
| 4. Available K (kg/ha) | 492.672 | | Flame photometric method (Jackson, 1967) |
| 5.pH (1:25 soil:water) | 6.5 | | Glass electrode pH meter (Piper,1967) |
| 6. EC (ds/m at 25°C) | 0.06 | | Solubridge method (Black, 1965) |

### 3.1.4 Cropping pattern

Rice is the principal crop in Chhattisgarh state, so is in Raipur district also. Other major crops are coarse grains such as wheat, maize, groundnut, pulses and oilseeds. Rice is predominantly grown under broadcast *Biasi* system during *kharif* but transplanted rice is also grown in a considerable area. Rice varieties grown generally are tall, long duration and photo-sensitive in nature which mature by mid November. As a result of withdrawal of south-west monsoon by the middle of september terminal droughts are often experienced at the reproductive stage of the rice crop, which is considered as the most crucial growth stage and any shortage of water during this stage generally adversely affects the rice yields. During *rabi* and summer seasons, a very small proportion of area is covered under the crops like wheat, chickpea, *Lathyrus*, urd, moong, pea, rapeseed/mustard, linseed, safflower, sunflower, lentil, groundnut, vegetables and sugarcane. In *rabi* season, *Lathyrus* is major crop in Raipur district and occupies about 5 per cent area. The study area is also suitable for growing mango, banana, guava and other fruits and a variety of vegetables.

Table 3.3 Cropping pattern in Raipur district

| Particulars | District Raipur(Area in ha) |
|---|---|
| **Kharif season** | |
| Paddy | 523098 (95.08%) |
| Jowar | 2699 (0.49%) |
| Maize | 2485 (0.45%) |
| Kodo-kutki | 7887 (1.43%) |
| Kulthi | 2198 (0.40%) |
| Tur | 1987 (0.36%) |
| Urd | 1036 (0.19%) |
| Moong | 2587 (0.48%) |
| Sesamum | 3435 (0.62%) |
| Soybean | 2733 (0.50%) |
| Sub total | 550145 (100) |
| Total | (87.36%) |
| **Rabi season** | |
| Lathyrus | 31521(10.04%) |
| Wheat | 6312 (10.04%) |
| Chickpea | 3997 (6.36%) |
| Urd | 5700 (9.06%) |
| Moong | 2097 (3.33%) |
| Pea | 1985 (3.16%) |
| Lentil | 1957 (3.10%) |
| Rapeseed/Mustard | 3905 (6.21%) |
| Linseed | 2342 (3.72%) |
| Safflower | 1897 (3.02%) |
| Sunflower | 1182 (1.88%) |
| Sub total | 62895(100) |
| Total | (9.99%) |

Source: District planning and statistics office, Raipur (2003).

### 3.1.5 Water resources

In Raipur district, the major sources of irrigation are dug well, tube well, tanks/ponds, canals etc. Out of these, canal is the main source of irrigation in Raipur district in (Table 3.4). However, canal irrigation is highly protective in nature i.e. it provides irrigation at the time of water stress condition existing during kharif when long dry spells usually occur due to breaks in monsoon, especially in the months of September and October. In Raipur district, canals contribute about 78 per cent area whereas tube-wells contribute 8.80 per cent area, ponds/tanks/other sources contribute nearly 5 per cent area and open wells contribute approximately 2 per cent area. Source-wise irrigated area in Raipur district is given in Table 3.4

Table 3.4 Source wise irrigated area in Raipur district
Source: District planning and statistics office Raipur (2003)

| S. No. | Particulars | Nos. | Area (ha) |
|---|---|---|---|
| 1 | Wells | 28307 | 5180<br>(2.14%) |
| 2 | Tubewells | 8134 | 21290<br>(8.80%) |
| 3 | Ponds/ Tanks | 7904 | 13096<br>(5.42%) |
| 4 | Reservoir | 125 | - |
| 5 | Canal | 136 | 188630<br>(77.97%) |
| 6 | Diesel pump | 5520 | - |
| 7 | Electric pump | 6165 | - |
| 8 | Others | - | 13722<br>(5.67%) |
| 9 | Net irrigation | 56291 | 241918 |

Note: Figures in the parentheses indicate the percentage value out of net irrigated area from all sources in Raipur district

## 3.2 Experimental Plot

### 3.2.1 Topographic Survey

As mentioned earlier, the present study was conducted on a field plot measuring about 1023.75 m² having a length of 35 m and width of 29.25 m. Before laying out the experiment, the field was surveyed and leveled. The contour survey was conducted on the experimental plot to determine its topographical features. Topographic survey was carried out using a dumpy level, measuring tape, levelling staff, spirit level etc. For conducting the contour survey, grids of 2m X 2m were set out on the field. The levels were then taken on each grid point by a dumpy level. The grids were then plotted to the scale on the map and the spot levels of the grids were marked on each grid point. The contours of desired values were then drawn by interpolation. On the plan, the relative altitudes of the grid points were represented by shading, hatches from lines or contour lines. Mostly wide spaced contour lines were obtained, which indicates an almost flat topography. The land slope in longitudinal and cross directions were obtained with the help of contour elevations. The existing longitudinal slope was determined as 0.6 per cent in south to north direction and the cross slope was computed as 0.3 per cent in west to east direction.

### 3.2.2 Land Levelling and Grading in Experimental Plot

In order to provide designed grade to the experimental plot, land leveling operation was conducted using a tractor drawn land leveler. Before starting the land leveling operation, land leveling design was made employing ‘Plane method’ which is described as under.

#### 3.2.2.1 Plane Method of Land Levelling Design

The plane method of land leveling design is most commonly used method for making land leveling design for the fields which are not much sloppy and when the field is to be graded to a true plane. Firstly, we determine the centroid of the field which the ratio of sum of the elevation of the grids to the numbers of grid points.

$$\text{Elevationof centroid } = \frac{\text{Sum of the elevation of the grid point}}{\text{Number of grid point}}$$

Then, the average elevation of the field was determined by adding elevations of all the grid points and dividing the sum by the number of points. After determining average elevation of the field, the slope of plane of best fit was computed by the following equation:

$$S = \frac{\sum(DH) - (\sum D)(\sum H)/n}{\sum(D^2) - (\sum D)^2/n}$$

Which,

S = slope of line in a plane (dimensionless)

D = distance from the reference line (m)

H = elevation of the grid point (m)

n = number of grid points

The slope of the plane was determined both in x- and y-directions. The elevation of any grid point was then calculated from the elevation of the centroid. Having determined the slope of the plane of best-fit, the designed formation levels, cuts and fills were estimated. The desired cut or fill at each grid point was obtained from the comparison of the original and the proposed elevations. When the proposed elevation is less than the original elevation of the ground surface, the difference will indicate the depth of cut at that point. When the formation level is higher than the original ground surface, the difference will show the depth of fill required at the point.

## 3.3 Experimental Details

### 3.3.1 Geometry of Experiment and Statistical Design

In the experimental plot, furrows were made by a tractor drawn ridger. A total number of 5 furrows were constructed for 5 different treatments and 3 replications of each treatment. In this way, total 15 furrows were constructed. A buffer strip of 1 m was left between the two treatments so that there is no or minimum effect of one treatment on the other treatment. The details of the experiment are given in Table 3.5 below.

Table 3.5 Geometric details of experimental plot and statistical design

| | | |
|---|---|---|
| Experimental plot area | : | 1023.75 m² (35 m X 29.25 m) |
| Furrow length | : | 35 m |
| Furrow bottom width | : | 0.15 m |
| Furrow top width | : | 0.9 m |
| Furrow depth | : | 0.25 m |
| Side slope | : | 2:1 |
| Bed slope | : | 0.2 per cent |
| Cross sectional area | : | 0.206 m² |
| Row to row spacing | : | 0.60 m |
| Plant to plant spacing | : | 0.45 m |
| Replications | : | Three |
| Date of nursery sowing | : | 15-01-2015 |
| Date of transplanting | : | Feb, 12 to Feb, 13 2015 |
| Harvesting (picking) | : | Multiple days |

### 3.3.2 Experimental Crop

In the present experiment, *brinjal* crop was grown on the ridges of each furrow. The seedlings of the *brinjal* were obtained from the Department of Horticulture, College of Agriculture Raipur. The age of these seedlings ranged from 25 to 30 days. The seedlings were transplanted on the ridges with 0.60 m spacing between the two seedlings. The details of the experimental *brinjal* crop are given in Table 3.6.

Table 3.6 Details of experimental brinjal crop

| | | |
|---|---|---|
| Name of crop | : | Brinjal |
| Common name | : | Baigan (hindi), Vangi (marathi) |
| Scientific name | : | Solanum melongena |
| Family | : | Solanaceae |
| Origin | : | India |
| Variety | : | Kashi Taru |

### 3.3.3 Fertilizer and Manure Application

FYM at a rate of 20 tons per hectare was applied at the time of field preparation. The recommended doses of fertilizers were applied as given in Table 3.7 in the form of urea, single super phosphate and muriate of potash respectively. Half dose of nitrogen and full amount of phosphorus and potassium were applied as basal dose at the time of transplanting. Remaining half dose of nitrogen was applied as top dressing twice at 30 days intervals.

Table 3.7 Nutrient application to brinjal crop

| Vegetable | Nutrient Applied | | |
|---|---|---|---|
| | N (kg/ha) | P (kg/ha) | K (kg/ha) |
| Brinjal | 125 | 75 | 60 |

### 3.3.4 Gap Filling

One week after transplanting of brinjal, gape filling was done in the place of dead seedlings to maintain optimum plant population in the experimental plot.

### 3.3.5 Treatment Details and Experimental Layout

The treatments included five types of mulches in three replications as shown in Table 3.8 below.

Table 3.8 Detail of treatments

| S. No. | Treatment Details | Notation Used |
|---|---|---|
| 1 | Plastic Mulch | $T_1$ |
| 2 | Straw mulch | $T_2$ |
| 3 | Saw dust mulch | $T_3$ |
| 4 | Soil mulch | $T_4$ |
| 5 | Without mulch (control) | $T_5$ |

The treatments were randomized as per the standard statistical procedure. The layout of the experiment is shown below.

**Plate 3.1 Field leveling for experiment layout**

**Plate 3.2 Making of furrows by ridger**

**Plate 3.3 View of brinjal nursery**

**Plate 3.4 Brinjal transplanting on furrow ridger**

**Plate 3.5 Irrigation in furrow for establishment of brinjal**

Plate 3.6 Furrow irrigation in brinjal

Plate 3.7 Laying of plastic mulch

Plate 3.8 Laying of straw mulch

Plate 3.9 View of saw dust mulch

Plastic 3.10 View of soil mulch

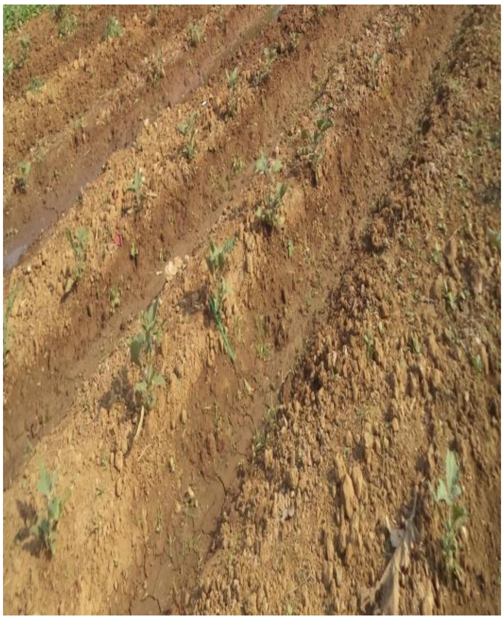


Plate 3.11 View of brinjal seedlings in no mulch treatment

Plate 3.12 Fruiting of brinjal with plastic mulch

Plate 3.13 Fruiting of brinjal without mulch

Plate 3.14 Picking of fruits

### 3.4 Furrow Discharge Measurement

The flow discharge in each furrow was measured by volumetric method. A drum having capacity of 140 liter was filled completely with water flowing out of the pipe at the head end of the furrows and time taken by the water flow to fill the drum was noted with the help of a stop watch. The capacity of drum divided by the time gave the inflow discharge. The average inflow discharge was thus determined as 2 litres per second.

### 3.5 Furrow Geometry

#### 3.5.1 Furrow Cross Section Area

Trapezoidal shaped furrows were made by using a tractor drawn ridger. The depth of furrow was measured by installing a hook gauge at every 5m distance along the furrow length and the average depth was found to be 0.25 m. Top width and bottom widths were also measured at the same distances. With a side slope of 1.5:1, the top width was measured as 0.9 m against the bottom width of 0.15 m. The actual measurements of furrow dimensions made in the experiment are given in Table 4.1 in chapter IV Results and Discussion.

#### 3.5.2 Furrow-Bed Slope

The bed or bottom slope of furrow was maintained as 0.2 per cent with the help of dumpy level and leveling staff.

#### 3.5.3 Flow Depth and Wetted Cross Section

Depths of water in furrows were also measured at 5,10,15,20, 25, 30 and 35 m distances in the furrow along the run of water during each irrigation. Flow cross sectional area, flow top width and wetted perimeter were measured in the field given in Table 4.2 in chapter IV Results and Discussion.

#### 3.5.4 Soil Infiltration

The infiltration is defined as the entry of water from the soil surface into the soil is called infiltration. An infiltration characteristic of the soil is one of dominant variables that greatly influence irrigation of the crops. Infiltration rate is the soil characteristic determining the maximum rate at which water can enter the soil under specific field conditions, including the presence of excess water. The infiltration rate decreases during irrigation. The rate of decreases is rapid initially and the infiltration rate then tends to approach approximately a constant value and this value is called basic infiltration rate. On the other hand, the total quantity of water that enters the soil in a given time is known as cumulative infiltration. Thus, the infiltration rate and the cumulative infiltration are the two basic parameters that are commonly used in evaluating the irrigation methods.

#### 3.5.4.1 Measurement of infiltration in experimental field

In the experiment, furrow infiltration was determined by volume balance method. The furrow was completely filled with water up to the top width and immediately, the water depths at different distances along the furrow length were measured. At the end, the furrow was blocked so that no water is allowed to escape as runoff. Then at different time intervals, the flow depths were measured at the same distances as was measured when the furrow was completely filled with water at the beginning. The difference of the two depths gave the depth of water infiltrated. This infiltration test was done in each treatment of the experiment at 1st, 2nd and 3rd irrigation to the *brinjal* crop raised in the experiment. The observations and calculations of infiltration tests are given in Appendix-B.

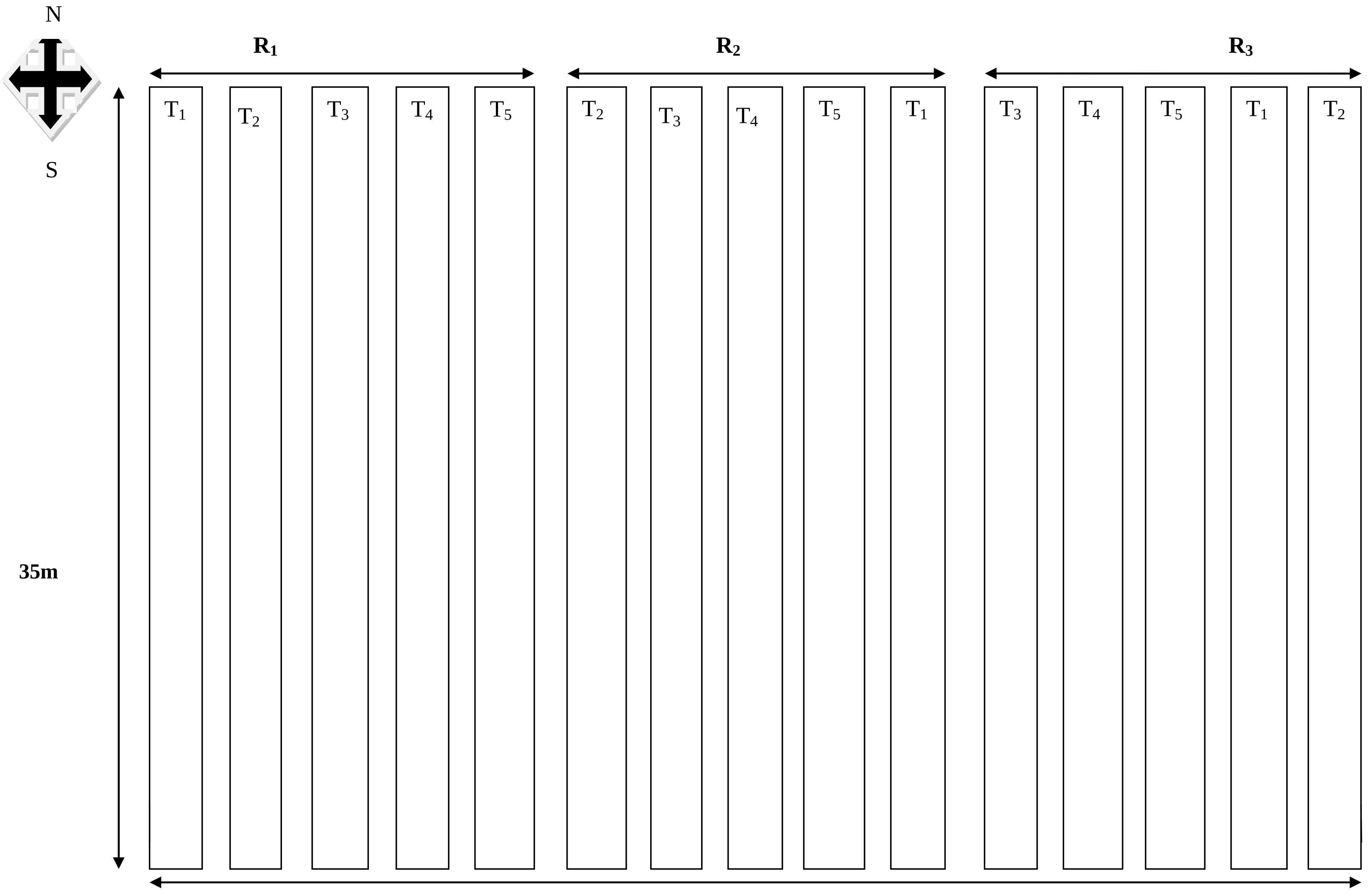


Fig. 3.2 Layout of field experiment

### 3.5.4.2 Development of infiltration model

An infiltration model was also developed using the observed data of the infiltration tests by employing modified Kostiakov model of infiltration which usually used for design purpose. According to Kostiakov model, the relationship between accumulated infiltration and elapsed time is expressed by the following equation:

$$y = at^{\alpha} + b \qquad \ldots (3.1)$$

Where, y = accumulated infiltration in time, t (cm)

t = elapsed time or infiltration opportunity time (min)

*a*, α and b are characteristic constants.

The infiltration rate at any time t is obtained by differentiating eq. (3.1) as follows:

$$\frac{dy}{dt} = a\alpha^{\alpha-1} \qquad \ldots (3.2)$$

The experimental data on accumulated infiltration versus elapsed time, when plotted on an ordinary graph paper, give a parabolic curve. When the same data are plotted on a log-log paper, a linear relationship is indicated. But some data on the initial stages of the experiment usually fall along a slight curved line. Thus, the constant *b* in modified Kostiakov model rectifies this slight deviation from the linear log-log relationship.

The values of these constants were determined by the method of average using the procedure suggested by Davis (1943). The first step in this method is to plot accumulated infiltration depth, $y$ on ordinate and elapsed time, t on *abscissa* on log-log paper. Now, two points $(t_1, y_1)$ and $(t_2, y_2)$ were selected on and near the extremities of the smooth curve representing the data. Then a point $y_3\sqrt{y_1}y_2$ was chosen and $y_3$ was read against $t_3$. The value of *b* was then determined using the following equation:

$$b = \frac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2y_3} \qquad \ldots (3.3)$$

The values of *a* and α were determined by taking the logarithm of the eq. (3.1) as follows:

$$y = at^{\alpha} + b$$

or $y - b = at^{\alpha}$

or, $\log(y - b) = \log a + \alpha \log t$

By substituting the observed values of $y$ and $t$ and computed value of $b$, several simultaneous equations were obtained. Using these simultaneous equations, the values of '$a$' and 'α' were determined. Thus, the equations for prediction of accumulated infiltration were developed as given in Table 3.9. These equations were developed based on the measured accumulated depths of infiltration and elapsed time as given in Appendix-B.

Table 3.9 Accumulated infiltration models developed for different treatments and irrigations

| Treatment | Developed accumulated infiltration models after irrigation | | |
|---|---|---|---|
| | $I^{st}$ irrigation | $II^{nd}$ irrigation | $III^{rd}$ irrigation |
| $T_1$ | $y = 2.663t^{0.168} - 1.181$ | $y = 2.327t^{0.181} - 0.779$ | $y = 2.373t^{0.179} - 0.866$ |
| $T_2$ | $y = 3.644t^{0.136} - 2.232$ | $y = 3.327t^{0.144} - 1.888$ | $y = 3.310t^{0.146} - 1.888$ |
| $T_3$ | $y = 3.137t^{0.150} - 1.687$ | $y = 3.512t^{0.139} - 2.101$ | $y = 3.514t^{0.139} - 2.101$ |
| $T_4$ | $y = 3.054t^{0.154} - 1.619$ | $y = 2.189t^{0.189} - 0.653$ | $y = 2.294t^{0.185} - 0.789$ |
| $T_5$ | $y = 3.162t^{0.150} - 1.727$ | $y = 3.239t^{0.147} - 1.797$ | $y = 3.235t^{0.148} - 1.797$ |

Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control)

Similarly, equations for prediction of average infiltration rate were developed using measured data of infiltration rate against elapsed time as given in Table 3.10. The measured data are given in Appendix-B.

Table 3.10 Average infiltration models developed for different treatments and irrigations

| Treatment | Developed average infiltration models after irrigation | | |
|---|---|---|---|
| | I$^{st}$ irrigation | II$^{nd}$ irrigation | III$^{rd}$ irrigation |
| $T_1$ | $y = 2.663t^{0.168-1}$ | $y = 2.327t^{0.181-1}$ | $y = 2.373t^{0.179-1}$ |
| $T_2$ | $y = 3.644t^{0.136-1}$ | $y = 3.327t^{0.144-1}$ | $y = 3.310t^{0.146-1}$ |
| $T_3$ | $y = 3.137t^{0.150-1}$ | $y = 3.512t^{0.139-1}$ | $y = 3.514t^{0.139-1}$ |
| $T_4$ | $y = 3.054t^{0.154-1}$ | $y = 2.189t^{0.189-1}$ | $y = 2.294t^{0.185-1}$ |
| $T_5$ | $y = 3.162t^{0.150-1}$ | $y = 3.239t^{0.147-1}$ | $y = 3.235t^{0.148-1}$ |

Note: $T_1$=Plastic mulch,$T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch,$T_5$=Without mulch (Control)

### 3.5.5 Advance of Waterfront

The advance rate of the water front down the furrow is the rate at which the waterfront advances through the furrow. The advance rate is influenced by both soil conditions (size, slope and roughness of the furrow) and inflow rate. For determining advance rate, stakes were fixed at every 5 m distance along the furrow length up to 35 m distance. The water was introduced into the furrow and time taken by the waterfront to reach the marked distances was recorded by a stop watch. In this way, observations of waterfront advance were taken in the experiment in all the treatments. The data of the waterfront advance and time are given in Appendix-C. The recorded data of time and advance distance of waterfront was plotted and the advance curve was obtained. A model was also developed for the prediction of time taken by the waterfront to advance the distance along the furrow length. The relation of time of waterfront advance with the advanced distance was found to be of a power form which conforms to the findings of Sirjani and Wallender (1989) also. The best-fit equation is follows:

$$t = aX^b \qquad \text{… (3.4)}$$

Where, X = distance moved by the water front in furrow (m)

t = time taken (min) by the water front to move the distance X ‘a’ and ‘b’ are the constants.

The results of the developed model were compared with the observed measurements of the waterfront advance.

In the experiment, the depths of water at the marked distances along the furrow were also measured. The data of these observations are given in Appendix-B.

The models developed for the prediction of time of recession of waterfront have been described and discussed in chapter IV Result and Discussion.

### 3.5.6 Recession of Waterfront

After the irrigation is cut off, the tail water recedes downstream of the furrow. The rate of recession of the tail water or waterfront was determined by recording the times at which water just disappears from the upstream end and recedes downstream past the furrow. The data of the waterfront recession and time are given in Appendix-A.

The model for predicting waterfront advance was also developed in the present study. The best-fit model as obtained is expressed as follows:

$$t = \alpha X^{\beta} \qquad \ldots (3.5)$$

Where, t = time of waterfront recession at distance X and $\alpha$ and $\beta$ are the constants.

The following models were developed for recession of waterfront are described and discussed in chapter IV Result and Discussion.

### 3.5.7 Infiltration Opportunity Time (Time of Ponding)

The difference between the time the waterfront reaches a particular point along the furrow and the time at which the tail water recedes from the same point is the infiltration opportunity time, or the time of ponding. The infiltration opportunity time at any point along the furrow is vertical distance between the advance and recession curves at the point.

## 3.6 Design of Furrow Irrigation System

Efficient furrow irrigation system is ensured by selecting proper combination of spacing, length and slope of furrows, irrigation water requirement based on 50% depletion of soil moisture content, type of crop grown, soil bulk density, soil infiltration etc. and determination of suitable size of the irrigation stream and duration of water application. The furrow spacing and bed slope have already been dealt with in earlier sections. The length of the furrow was limited to the available field size. Thus, the length of each furrow was limited to 30 m. Other parameters as determined in the study for an appropriate design of the furrow irrigation system are described in succeeding sections.

### 3.6.1 Soil Moisture Content

For taking soil moisture from randomly selected points on the ridge bed of each furrow, the soil samples were collected with the help of screw auger and were kept in aluminum soil moisture boxes. The weight of these boxes with soil samples was determined immediately by using electronic balance. Then, they were placed in an oven at 105 °C for 24 hours for drying. After drying for 24 hours, the boxes with dried soil samples were again weighed in order to know the weight of moisture of the soil samples. Soil samples were taken before irrigation and after irrigation and moisture content was determined as follows:

$$\text{Soil moisture (\%)} = \frac{\text{Weight of moist soil} - \text{Weight of oven dried soil}}{\text{Weight of oven dried soil}} \text{X}100$$

Moisture contents were calculated for different soil layers (0-10, 10-12 and 12-15 cm) and averaged to know the average value of the soil moisture content. Soil moisture contents were determined before and after irrigation for 1st, 2nd, and 3rd irrigation.

### 3.6.2 Soil Bulk Density

The value of bulk density was determined by using the mass of soil sample and its volume as already taken for moisture content determination. The bulk density of the soil was determined as follows:

$$Bulk\ Density\ \left(\frac{g}{cc}\right) = \frac{Mass\ of\ soil\ sample}{Volume\ of\ soil\ sample}$$

The bulk density of the soil of the experimental plot, thus, was worked out as 1.44 g/cc.

### 3.6.3 Irrigation Requirement

After the irrigation, soil moisture content was determined on daily basis to find out the level of 50% depletion of soil moisture before next irrigation. The field capacity (FC) and permanent wilting point (PWP) of the soil were adopted from the reports of the Department of Agronomy, College of Agriculture, Raipur as given for similar soils of the IGKV farm. The values of *FC* and *PWP* reported as 28.6% and 13.6%, respectively. These values of *FC* and *PWP* were used in this study to determine the net irrigation requirement of *Brinjal.* The effective root zone depth for the selected variety of *brinjal* was taken as 0.45 m as reported in literature (Anonymous 2011).

The net irrigation requirement is the net depth of irrigation to be given to the crop excluding precipitation, carry-over soil moisture or groundwater contribution or any other gain in soil moisture, which is required to bring the soil moisture in the effective root zone to its filed capacity after 24 hours of irrigation. In other words, the net depth of irrigation is the difference between the field capacity and the soil moisture content in the root zone before starting irrigation. The following formula was used to determine the net irrigation requirement of *brinjal*:

$$d_n(mm) = \frac{(FC - PWP)}{100} \times BD(1 - CP) \times D \times (1000) \qquad \ldots (3.6)$$

Where $d_n$ = net depth (in mm) of water to be applied in one irrigation

$FC$ = field capacity by weight, %

$PWP$ = permanent wilting point by weight, %

$BD$ = bulk density of soil, g/cc

$CP$ = critical point i.e. soil moisture depletion level, fraction (i.e. 0.5)

$D$ = effective root zone depth, m

The required parameters were substituted in above formula to find out the net depth of irrigation to be applied to *brinjal* plant. Therefore,

$$d_n(mm) = \frac{(28.6 - 12.4)}{100} \times 1.44(1 - 0.5) \times 0.45 \times (1000) = 52.48 \text{ mm}$$

Say, 52 mm

$$d_g = \frac{d_n}{E_a}$$

Where, $d_g$ = gross depth of irrigation

$E_a$ = application efficiency of furrow irrigation system (assuming, 75%)

The gross irrigation depth thus was calculated as,

$$d_g = \frac{52.48}{0.75} = 69.97 \text{ mm, say 70 mm or 7 cm.}$$

### 3.6.4 Stream Size and Cutback Stream

In furrow irrigation, the size of the furrow stream i.e. furrow discharge is the one factor which can be varied as per the irrigation requirement. The size of the furrow stream usually varies from 0.5 to 2.5 lps. To obtain high irrigation uniformity, the largest stream of water that will not cause erosion is used in each furrow at the beginning of irrigation. The reason behind using large stream size is that the entire furrow should be wet as quickly as possible so as to enable the soil to absorb water evenly through the entire furrow length. After the water reaches the lower end of the furrow, the stream size is to be reduced or cutbacks so that it will just keep the furrow wet throughout its length with a minimum waste at the furrow end. This cutback stream continues to until the required amount of water has been applied.

The theoretical maximum size of irrigation stream that can be used at the start of the irrigation has to be limited by considerations of erosion in the furrows, overtopping of furrows and prevention of runoff at the downstream end of the furrows. Thus the maximum non-erosive flow rate i.e. stream size was estimated by the following empirical equation (Michael, 1978):

$$q_m = \frac{0.6}{S}$$

Where, $q_m$ = maximum non-erosive stream size, lps

S = slope of the furrow, %

The slope of the furrows as determined earlier in land leveling design was computed to be 0.2%. Thus, the maximum stream size was calculated as follows:

$$q_m = \frac{0.6}{0.2} = 3 \text{ lps}$$

Hence, at 1st irrigation, the maximum stream size of 3 lps was given in each furrow for the duration until the waterfront reached the end of the furrow. the stream size was reduced to 2 lps until the required amount of water has been applied. The duration up to which this stream size was applied in the furrows was determined by the following formula (Michael, 1978):

$$t = \frac{d \times w \times L}{q \times 360}$$

Where, $t$ = duration of irrigation (elapsed time), h

$d$ = average gross depth of water to be applied, cm

$q$ = stream size, lps

$w$ = furrow spacing, m

$L$ = furrow length, m

All the input values were substituted except $t$ into the above equation to calculate $t$. The input values as recorded or estimated were:

$q$ = 2 lps; $d$ = 7 cm; $w$ = 1.05 m; $L$ = 35 m

$$\therefore t = \frac{7 \times 1.05 \times 35}{2 \times 360} = 0.357 \text{ h, i.e. } 21.42 \text{ min, say } 21\text{min}$$

This means to apply the required net depth of irrigation of 5.2 cm, assuming application efficiency of furrow irrigation as 75%, the stream of 2 lps was applied in each furrow for a duration of 21 min i.e. 1260 sec.

**3.6.5 Volume of Water Applied**

As computed above, the stream of 2 lps was applied to each furrow for 21 min, Therefore, the volume ($V$) of water applied was determined from the stream size i.e. discharge ($q$) and time ($t$) of the irrigation water given in the furrow as follows:

$$V = q \times t$$

Volume of water applied in each furrow = 2 x 1260 = 2520 liters =2.52 m$^3$

Area of one furrow = 36.75 m$^2$

$\therefore$ Actual depth of water applied in each irrigation = $\frac{Volume}{Area} = \frac{2.52}{36.75} = 0.0685$ m

= 6.85 cm

In all, 6 irrigations were given to the *brinjal* crop during entire crop duration.

**3.7 Irrigation Efficiencies**

Irrigation efficiency indicates how efficiently the available water supply is being utilized in an irrigation method. The designs of the irrigation system, the degree of land preparation and skill and care of irrigator are the important factors influencing irrigation efficiency. Loss of irrigation water occurs mainly in the conveyance and distribution system, non-uniform application and distribution of water over the field and percolation below root zone. This loss can be held to a minimum by adequate planning of irrigation system, proper design of irrigation system, adequate land preparation and efficient operation of the irrigation system. In this study, application efficiency, distribution uniformity and water-use efficiencies were determined based on the field data on quantum of water applied, water stored in the root zone and ultimately the yield of the *brinjal*.

### 3.7.1 Water Application Efficiency

How efficiently the water has been applied by the irrigation system is measured in terms of water application efficiency of the irrigation system. Hart, et al (1979) specified that the water application efficiency ($E_{a)}$ must not be less than 60% for satisfactory furrow irrigation performance. The application efficiency of the furrow irrigation system for each of the treatments was, thus determined using the following formula:

$$E_a = \frac{W_s}{Wf} \times 100 \qquad \text{… (3.7)}$$

Where, $E_a$ = water application efficiency, %

$W_s$ = water stored in crop root zone, cm

$W_f$ = water delivered at the head end of the furrows, cm

Water application efficiencies for all the treatments were determined and are given and discussed in Chapter IV Results and Discussion.

### 3.7.2 Water Distribution Efficiency

Not only is the application of the right amount of water to the field is important but also its uniform distribution over the entire field is equally important. Water distribution efficiency ($E_d$) must not be less than 70% for satisfactory furrow irrigation performance (Hart, et al 1979). Thus, water distribution efficiency of each treatment was determined using the following formula:

$$E_d = (1 - \frac{\bar{y}}{\bar{d}}) \times 100 \qquad \text{… (3.8)}$$

Where, $E_d$ = Water distribution efficiency, %

$\bar{d}$ = Average depth of water stored in root zone along the furrow after irrigation, cm

$\bar{y}$ = Average numerical deviation from $\bar{d}$ , cm

### 3.7.3 Water-Use Efficiency

The utilization of water by the crop is generally described in terms of water-use efficiency in kg/ha-cm or q/ha-cm. water-use efficiency is expressed in two ways- crop water-use efficiency and field water-use efficiency. In the study, both the efficiencies were determined.

### 3.7.3.1 Field Water-Use Efficiency

Field water-use efficiency is the ration of crop yield to the total amount of water used in the field and is expressed as follows:

$$W_E = \frac{Y}{WR} \qquad \ldots (3.10)$$

Where, $W_E$ = Field water-use efficiency, q/ha-cm

$Y$ = Yield of the crop, $q$

$WR$ = Water requirement of the crop in cm over one hectare area.

The computed values of all above efficiencies are given in Chapter IV Results and Discussion.

### 3.8 Economic Analysis

The economic analysis of the experiment was made to find out the benefit cost ratio of brinjal production under furrow irrigation with different mulches. The total cost of cultivation was estimated for each treatment considering the actual cost of the various agricultural inputs used, labour requirement, land preparation, insecticides and pesticides used, brinjal seedlings etc. The gross benefit was computed based on the current selling price (year-2014-2015) of brinjal in the market. Based on the total cost of cultivation and gross profit, the benefit-cost ratio for each treatment was determined.

# CHAPTER-IV
# RESULTS AND DISSCUSSION

The study was conducted during *Rabi* season 2014-2015 on "Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches Material". The analysis of the experiment has been carried out in three phases which include hydraulic evaluation of furrow irrigation with different mulches in brinjal, performance evaluation of different types of mulching materials and the economic analysis of furrow irrigation system for production of brinjal at the experimental field of faculty of agricultural engineering, IGKV Raipur. This chapter discusses obtained in the study. The result of the study have been thoroughly discussed and corroborated in the context of finding in following heads.

## 4.1 Hydraulic performance of furrow irrigation

The hydraulic analysis includes determination of hydraulic parameters advance and recession of waterfront infiltration characteristics, moisture distribution pattern, and irrigation efficiencies. Before making experimental observations, the geometry of furrows is described herein.

### 4.1.1 Furrow geometry

The furrow cross-section was measured prior to each irrigation treatment and measurement were made to determine the wetted cross-sectional area, wetted perimeter and top width with respect to depth of flow during each irrigation events. Which are given in Table 4.1 below.

The depth, bottom width and top width of furrow were measured at different sections at the 5 m intervals of distance along the flow run. The depth of the furrow varied from 0.262 m to 0.239 m giving an average furrow depth as 0.25 m. bottom width also varied from a minimum as 0.139 m to a maximum as 0.163 m and the average bottom width of the furrow was found to 0.15 m. similarly, top width of the furrow had a variation ranging from a minimum as 0.852 m to a maximum as 0.955 m resulting in an average of 0.9 m. The average bed slope of the furrows was found to be 0.2 percent.

Table 4.1 Furrow dimensions at different distances along the length

| S.N. | Distance (m) | Depth (m) | Bottom width (m) | Top width (m) |
|---|---|---|---|---|
| 1 | 5 | 0.262 | 0.139 | 0.925 |
| 2 | 10 | 0.271 | 0.142 | 0.955 |
| 3 | 15 | 0.243 | 0.163 | 0.892 |
| 4 | 20 | 0.235 | 0.147 | 0.852 |
| 5 | 25 | 0.245 | 0.158 | 0.893 |
| 6 | 30 | 0.255 | 0.155 | 0.92 |
| 7 | 35 | 0.239 | 0.146 | 0.863 |
| Ave. |  | 0.25 | 0.15 | 0.9 |

After each irrigation through furrows, the flow geometry was also determined by measuring flow depth, bottom width, top flow width along the furrow length of 35 m at 5 m intervals. The flow depth in the furrows ranged from a minimum depth of 0.180 m to a maximum depth of 0.220 m and the average flow depth was found as 0.20 m. Top width of flow section varied from 0.682 m to 0.818 m with an average value of 0.75 m. These measurements were used to calculate flow area in the furrow at different sections with 5 m intervals. It was found that flow area varied from 0.0742 m$^2$ to 0.1074 m$^2$ with an average flow area as 0.73 m$^2$. The wetted perimeter also showed a variation ranging from 0.791 m to 0.951 m with an average wetted perimeter of 0.87 m. The furrow cross sectional area was measured prior to each irrigation and relationship were developed to determine wetted cross sectional area, wetted perimeter and top width with respect to depth of flow during each irrigation events up to three irrigations.

Table 4.2 Flow dimensions, flow cross sectional area and wetted perimeter along the furrow length

| S.N. | Distance (m) | Flow depth (m) | Bottom width (m) | Top flow width (m) | Flow area ($m^2$) | Wetted perimeter (m) |
|---|---|---|---|---|---|---|
| 1 | 5 | 0.21 | 0.139 | 0.769 | 0.0953 | 0.896 |
| 2 | 10 | 0.18 | 0.142 | 0.682 | 0.0742 | 0.791 |
| 3 | 15 | 0.21 | 0.163 | 0.793 | 0.1004 | 0.92 |
| 4 | 20 | 0.187 | 0.147 | 0.708 | 0.0799 | 0.821 |
| 5 | 25 | 0.22 | 0.158 | 0.818 | 0.1074 | 0.951 |
| 6 | 30 | 0.194 | 0.155 | 0.737 | 0.0865 | 0.854 |
| 7 | 35 | 0.2 | 0.146 | 0.746 | 0.8920 | 0.867 |
| Ave. |  | 0.20 | 0.15 | 0.75 |  | 0.87 |

The best-fit statistical relationships between these parameters with respect to flow were found as a power relationship as shown in Table 4.3 below.

Table 4.3 Relationship between furrow cross section area, wetted perimeter, and top width with respect to depth of flow

| S. No. | Furrow parameter | Functional relationship | Coefficient of determination |
|---|---|---|---|
| 1. | Cross section area (A) in $cm^2$ | $A= 1..6146d^{1.7939}$ | $R^2=0.982$ |
| 2. | Wetted perimeter (W) in cm | $W=3.6685d^{0.8934}$ | $R^2=0.9818$ |
| 3. | Top width (T) in cm | $T=3.0738d^{0.8764}$ | $R^2=0.9743$ |

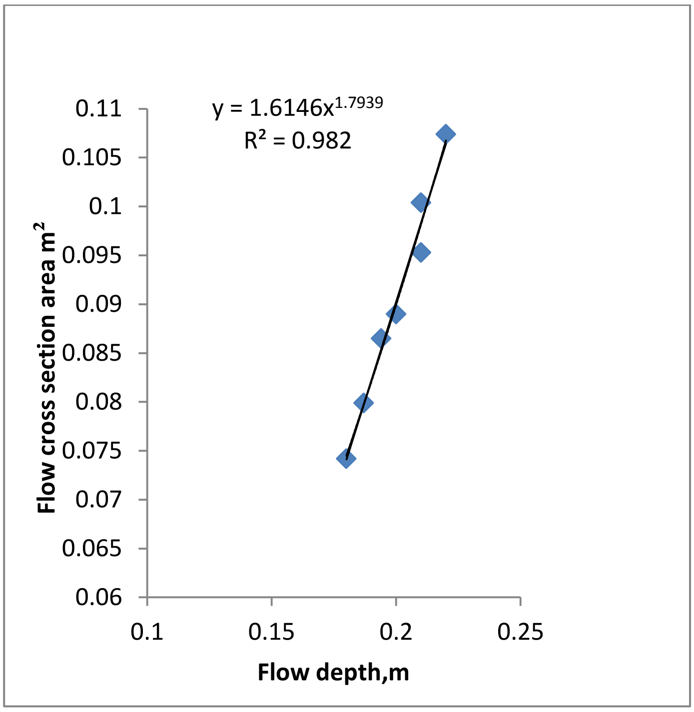


Fig. 4.1Relationship between flow cross section area to flow depth

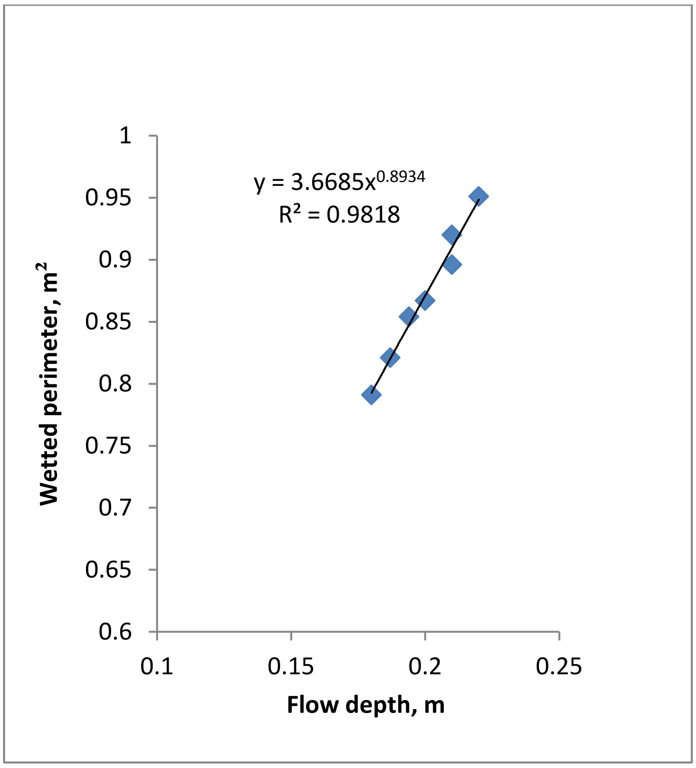


Fig. 4.2 Relationship between wetted perimeters to flow depth

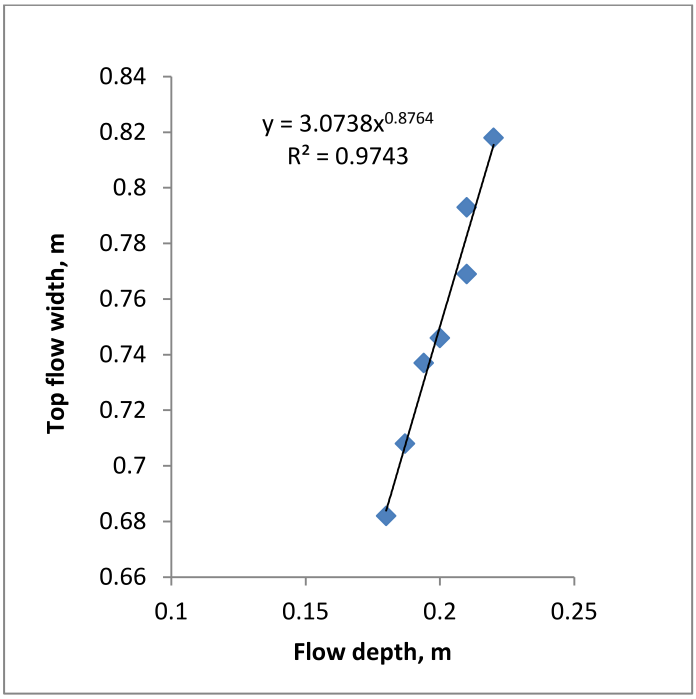


Fig. 4.3 Relationship between top flow widths to flow depth

### 4.1.2 Advance and Recession of Waterfront

After the water was let off in the furrows, the time of waterfront advance was recorded at 5 m interval of distance at 0, 5, 10, 15, 20, 25, 30 and 35 m length of the furrows. The stream was cut off when waterfront reached to the end of the furrows i.e. 35 m distance. In the similar manner, the times of disappearance of waterfront i.e. recession times were recorded in each treatment. The data on times of water front advance and recession in furrows during 1st, 2nd and 3rd for all the treatments are given in Appendix-A.

The relationships were developed both for advance time and recession time with respect to distance. The power equations were fitted to develop relationships. The power function was found as the best fit giving higher values of coefficient of determination ($R^2$) both for advance time v/s distance, as well as recession time v/s distance for all treatments as given in Table 4.4 and Table 4.5 respectively. The waterfront advance and recession curves were also drawn for elapsed time corresponding to distance along the furrow length and are shown in fig 4.1 for each treatment during 1st, 2nd and 3rd irrigation. It can be seen from figures that in furrow irrigated bed system advance and recession curves were more or less parallel for stream size of 2lps for all furrow irrigated beds indicating that stream size of 2lps provided uniform infiltration opportunity time along the furrow length.

Table 4.4 Models developed in the study for prediction of time of waterfront advance.

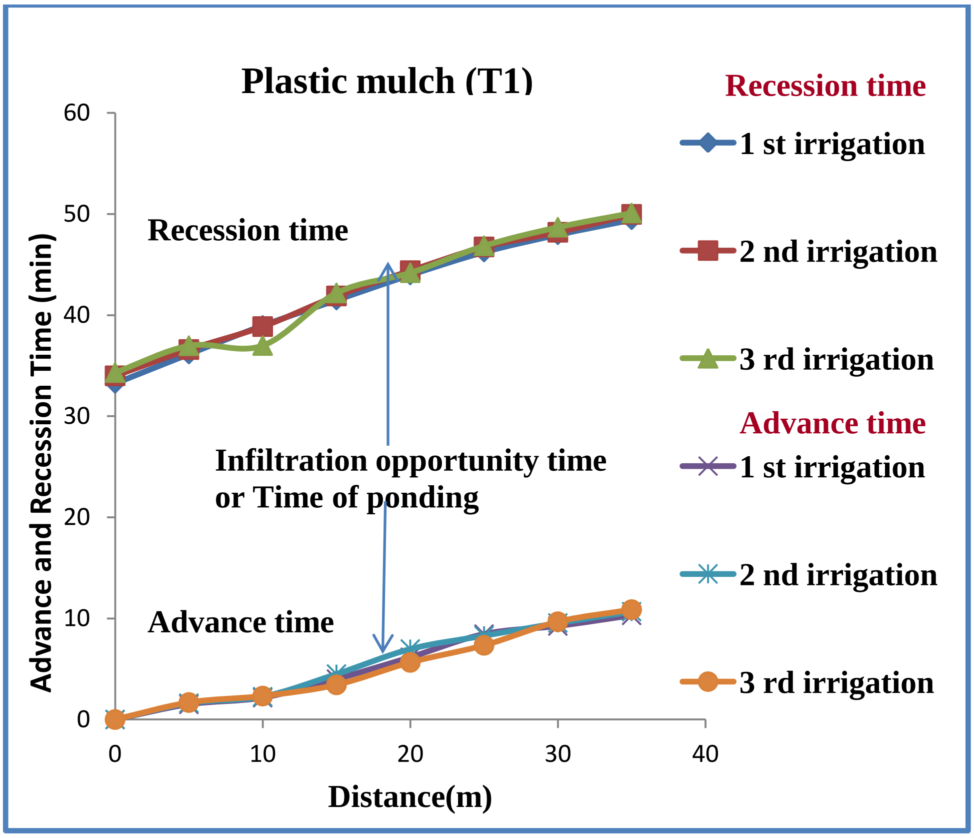
| Treatment | Developed waterfront advance models after irrigation | | |
|---|---|---|---|
| | First irrigation | Second irrigation | Third irrigation |
| $T_1$ | $t = 0.226x^{1.085}$<br>($R^2$=0.969) | $t = 0.258x^{1.058}$<br>($R^2$=0.966) | $t = 0.262x^{1.027}$<br>($R^2$=0.955) |
| $T_2$ | $t = 0.282x^{0.987}$<br>($R^2$=0.918) | $t = 0.263x^{1.017}$<br>($R^2$=0.931) | $t = 0.291x^{0.999}$<br>($R^2$=0.937) |
| $T_3$ | $t = 0.266x^{1.024}$<br>($R^2$=0.935) | $t = 0.304x^{0.994}$<br>($R^2$=0.966) | $t = 0.332x^{0.944}$<br>($R^2$=0.946) |
| $T_4$ | $t = 0.335x^{0.965}$<br>($R^2$=0.956) | $t = 0.314x^{0.981}$<br>($R^2$=0.957) | $t = 0.278x^{1.018}$<br>($R^2$=0.959) |
| $T_5$ | $t = 0.331x^{0.962}$<br>($R^2$=0.955) | $t = 0.275x^{1.025}$<br>($R^2$=0.954) | $t = 0.322x^{0.967}$<br>($R^2$=0.969) |

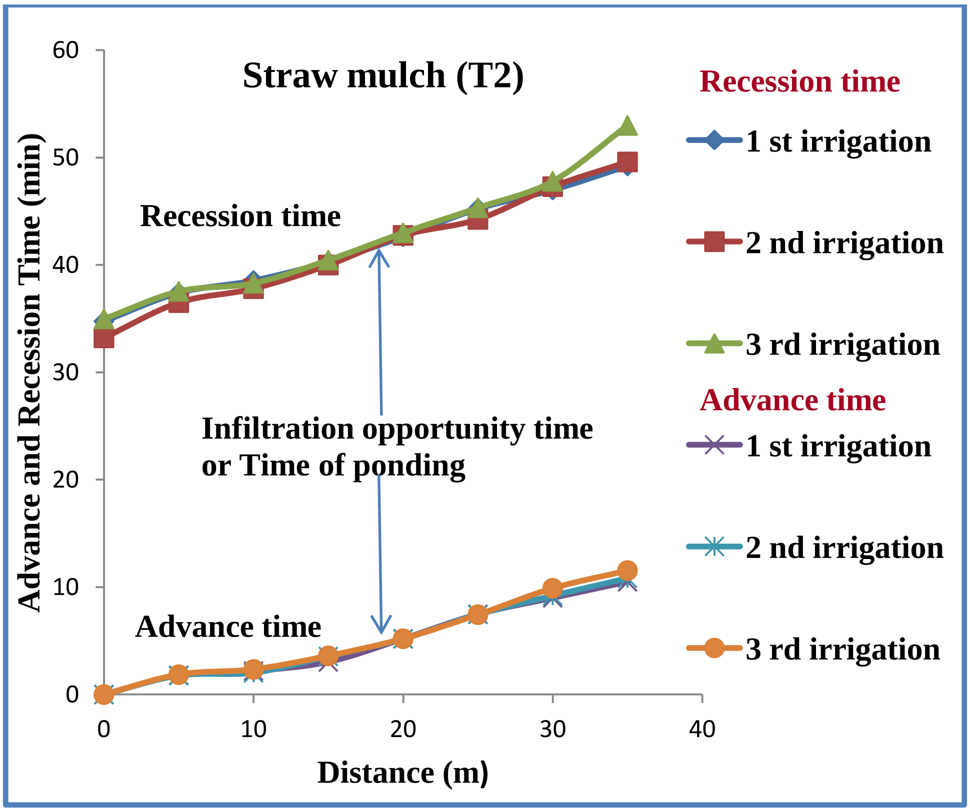
Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).

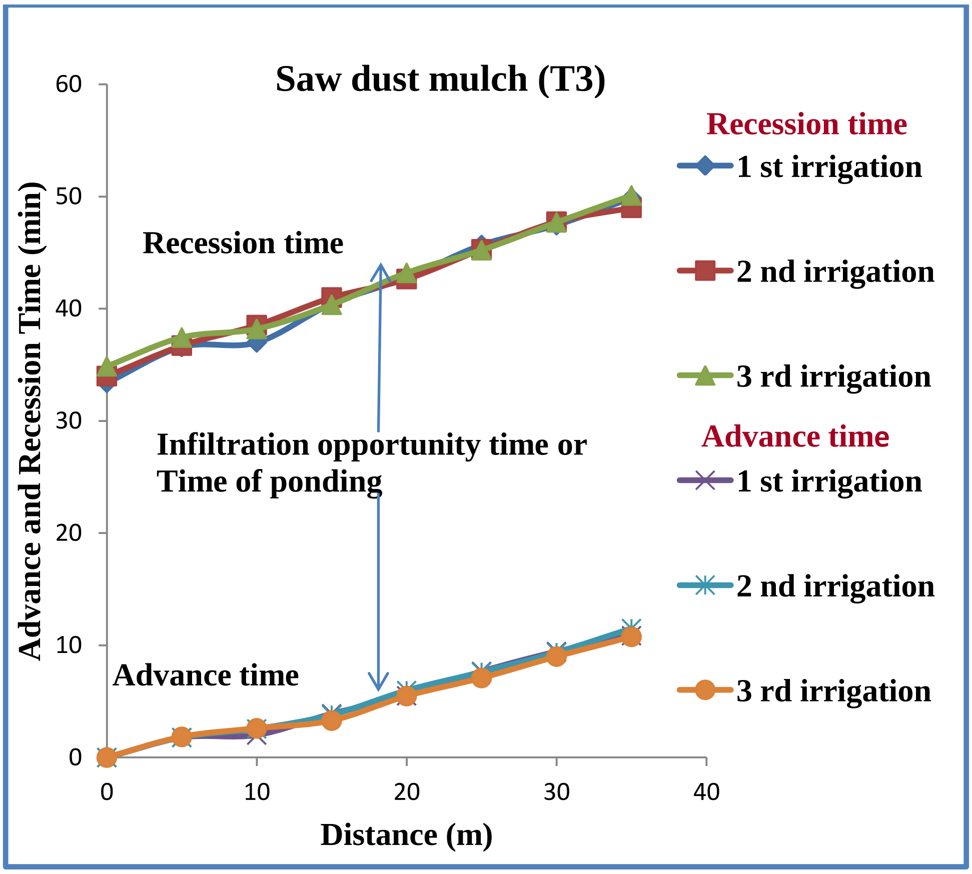
Table 4.5 Models developed in the study for prediction of time of waterfront recession.

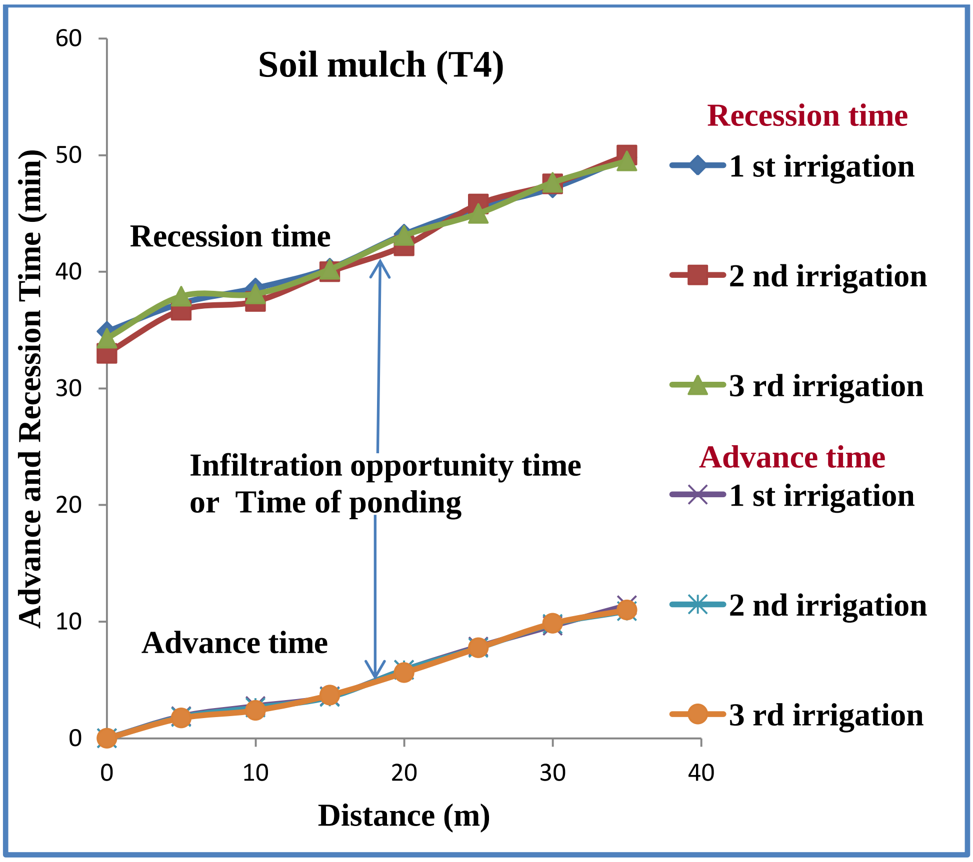
| Treatment | Developed waterfront recession models after irrigation | | |
|---|---|---|---|
| | First irrigation | Second irrigation | Third irrigation |
| $T_1$ | $t = 27.14x^{0.164}$<br>($R^2$=0.979) | $t = 27.296x^{0.165}$<br>($R^2$=0.971) | $t = 26.662x^{0.172}$<br>($R^2$=0.912) |
| $T_2$ | $t = 28.488x^{0.143}$<br>($R^2$=0.899) | $t = 27.097x^{0.158}$<br>($R^2$=0.907) | $t = 27.119x^{0.166}$<br>($R^2$=0.834) |
| $T_3$ | $t = 26.555x^{0.167}$<br>($R^2$=0.901) | $t = 27.779x^{0.153}$<br>($R^2$=0.939) | $t = 28.892x^{0.153}$<br>($R^2$=0.888) |
| $T_4$ | $t = 28.119x^{0.149}$<br>($R^2$=0.906) | $t = 26.724x^{0.164}$<br>($R^2$=0.888) | $t = 28.532x^{0.144}$<br>($R^2$=0.864) |
| $T_5$ | $t = 28.321x^{0.148}$<br>$R^2$=(0.912) | $t = 26.655x^{0.166}$<br>($R^2$=0.920) | $t = 28.804x^{0.141}$<br>($R^2$=0.901) |

Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).


Plastic mulch (T1)
Recession time
1 st irrigation
2 nd irrigation
3 rd irrigation
Advance time
1 st irrigation
2 nd irrigation
3 rd irrigation
Recession time
Infiltration opportunity time
or Time of ponding
Advance time
Advance and Recession Time (min)
0
10
20
30
40
50
60
0
10
20
30
40
Distance(m)


Straw mulch (T2)
Recession time
1 st irrigation
2 nd irrigation
3 rd irrigation
Advance time
1 st irrigation
2 nd irrigation
3 rd irrigation
Recession time
Infiltration opportunity time
or Time of ponding
Advance time
Advance and Recession Time (min)
0
10
20
30
40
50
60
0
10
20
30
40
Distance (m)


Saw dust mulch (T3)
Advance and Recession Time (min)
Distance (m)
0
10
20
30
40
50
60
0
10
20
30
40
Recession time
Infiltration opportunity time or
Time of ponding
Advance time
Recession time
1 st irrigation
2 nd irrigation
3 rd irrigation
Advance time
1 st irrigation
2 nd irrigation
3 rd irrigation


Soil mulch (T4)
Advance and Recession Time (min)
Distance (m)
0
10
20
30
40
50
60
0
10
20
30
40
Recession time
Infiltration opportunity time
or Time of ponding
Advance time
Recession time
1 st irrigation
2 nd irrigation
3 rd irrigation
Advance time
1 st irrigation
2 nd irrigation
3 rd irrigation

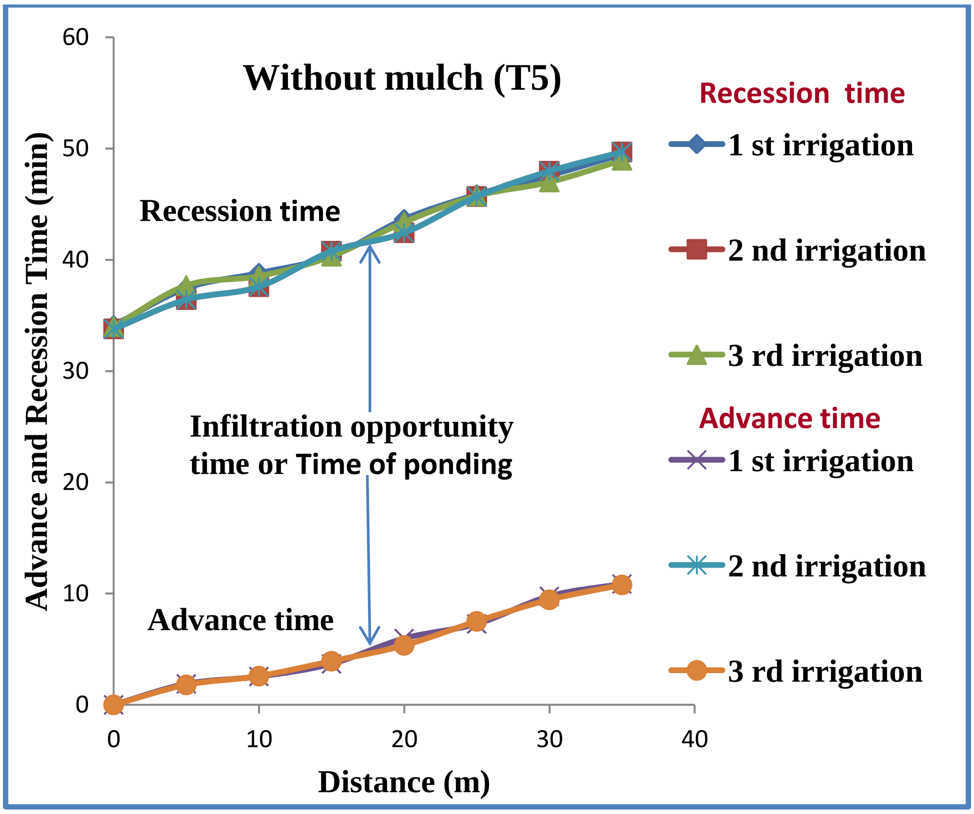


Fig. 4.4 Advance and recession curves for furrow irrigation system during 1st, 2nd and 3rd irrigation

### 4.1.3 Depth of Water Applied

The net depth of water applied was found 5.248 cm, gross depth of water applied was found 6.997 cm and actual depth of water applied in each irrigation was found 6.85 cm.

### 4.1.4 Infiltration Characteristics

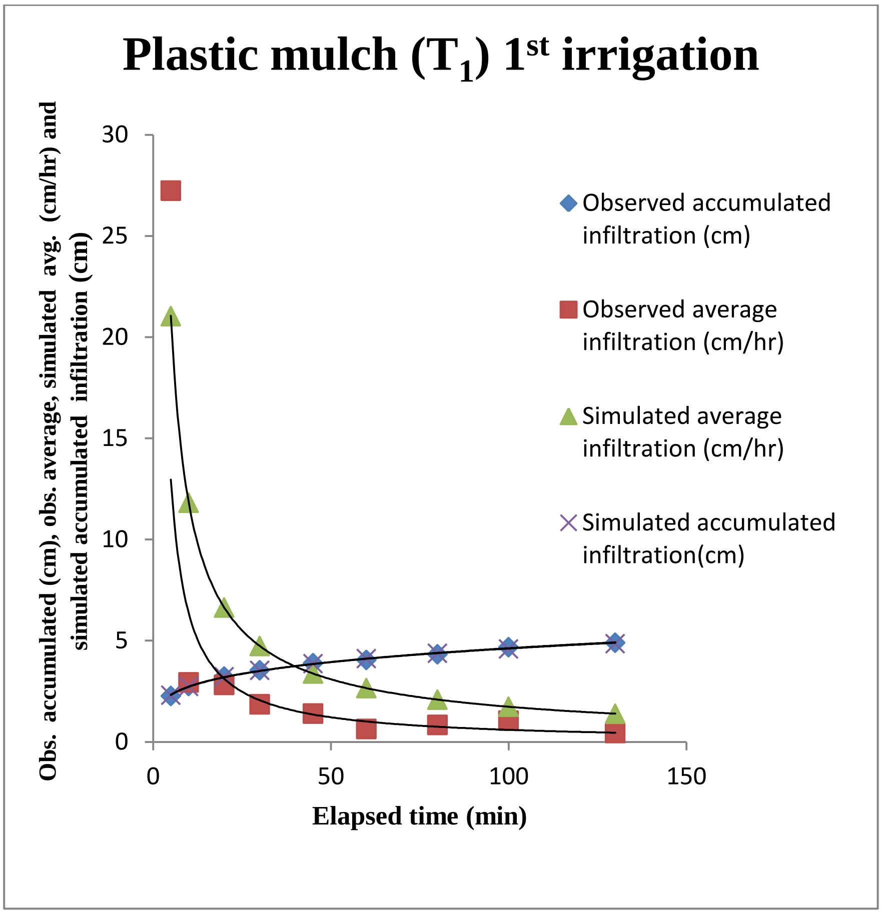
Infiltration characteristics in furrow irrigation system were determined by volume balance method at each irrigation. The basic infiltration rates during each treatment $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ are given in Table 4.6 at 1st, 2nd and 3rd irrigation, respectively in chapter III materials and methods. The infiltration observations recorded (Appendix-B) were used for deriving the relationship between accumulated infiltration with elapsed time and average infiltration with elapsed time. The relationships between accumulated infiltration and elapsed time were found in the form of power function which is shown in Fig. 4.5. The figures show that the change in infiltration rate during initial 25 minutes was abrupt; thereafter, it was gradual between 25-60 minutes and attained approximately a constant value after 130 minutes. The values of this constant infiltration rates known as the basic infiltration are given in Table 4.6.

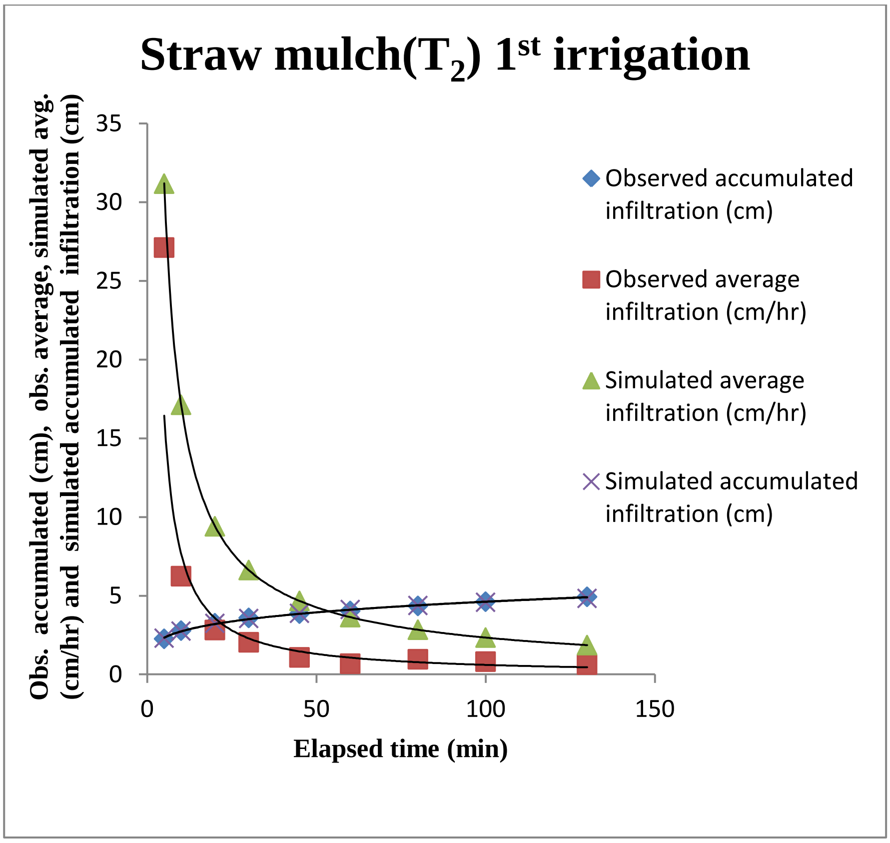
Table 4.6 Basic infiltration rate during 1st, 2nd and 3rd irrigation

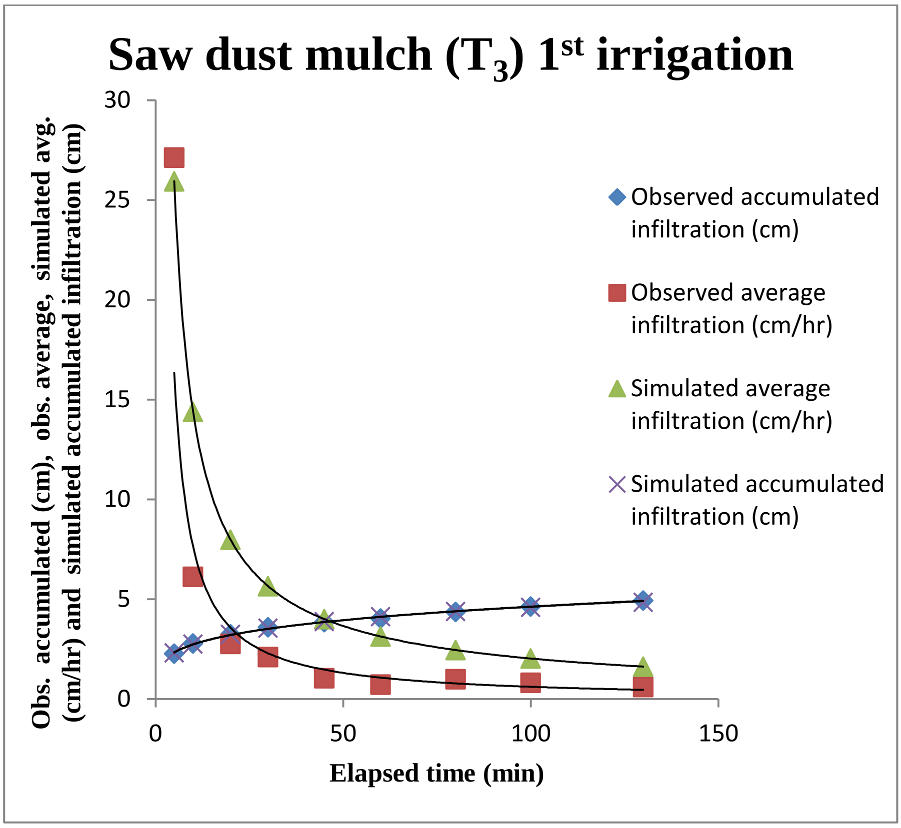
| Irrigation | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
|---|---|---|---|---|---|
| 1st | 0.44 | 0.62 | 0.6 | 0.48 | 0.46 |
| 2nd | 0.56 | 0.62 | 0.64 | 0.52 | 0.52 |
| 3rd | 0.58 | 0.6 | 0.66 | 0.52 | 0.5 |

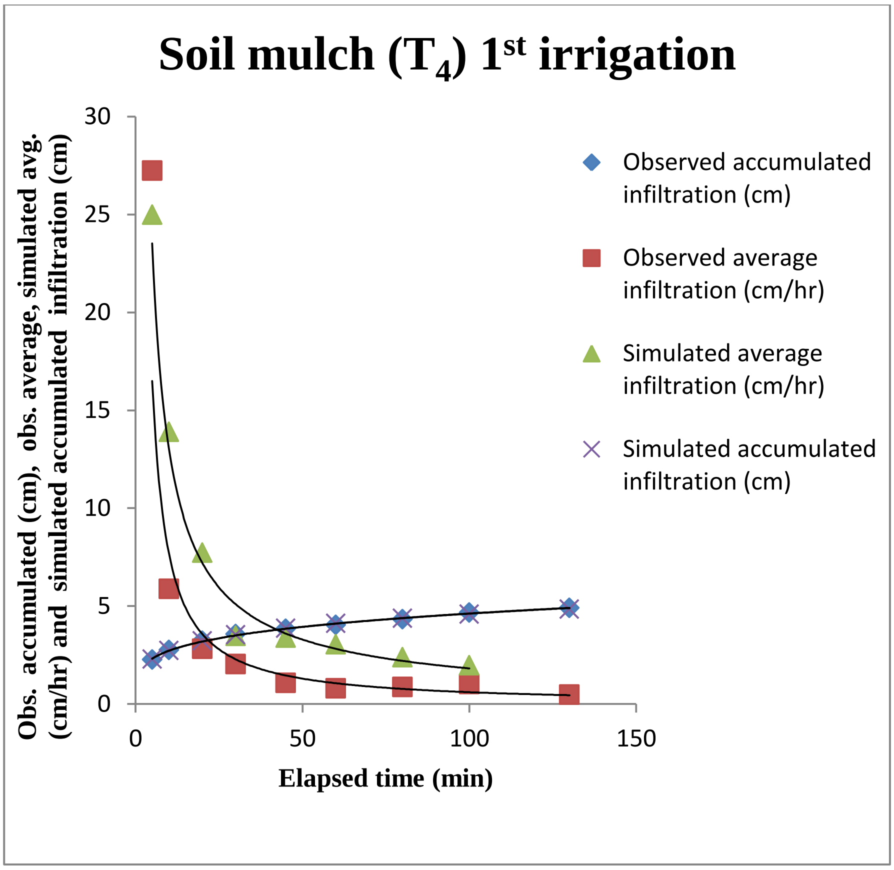
Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).

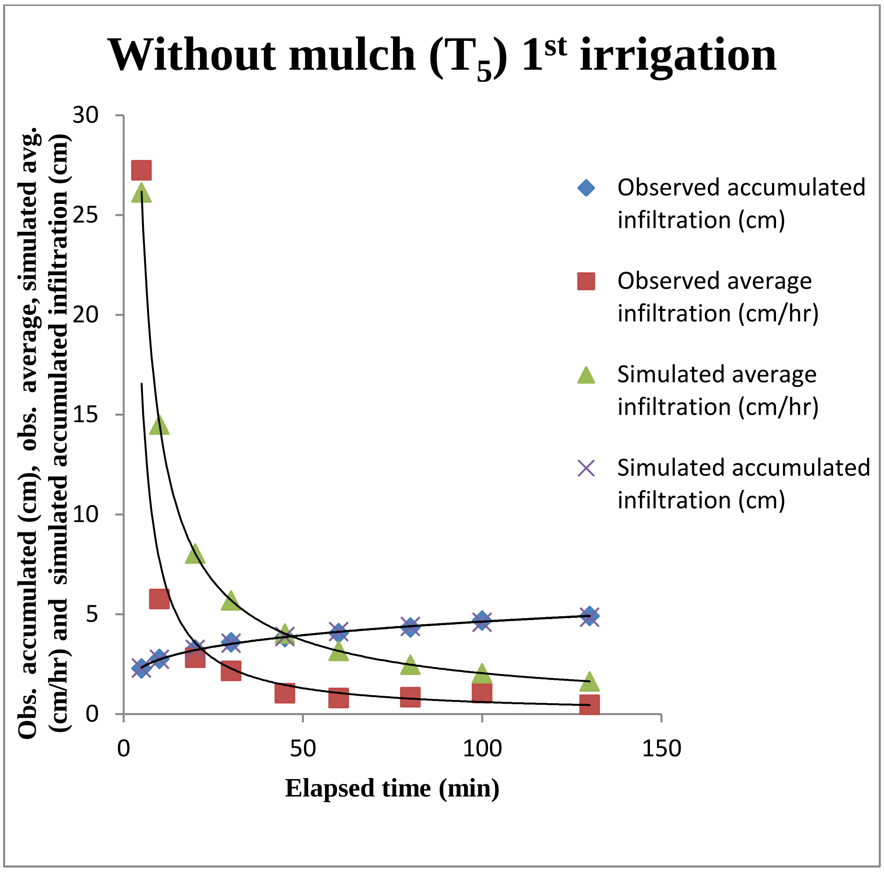
It is observed from Table 4.6 that in treatment $T_1$ the basic infiltration rate showed a large variation from 1st, 2nd and 3rd irrigation as compared to other treatments. It might be due to the fact that in treatment $T_1$, the polythene mulch increased the time to attain a basic infiltration because the escape of the moisture was minimum due to polythene sheets.

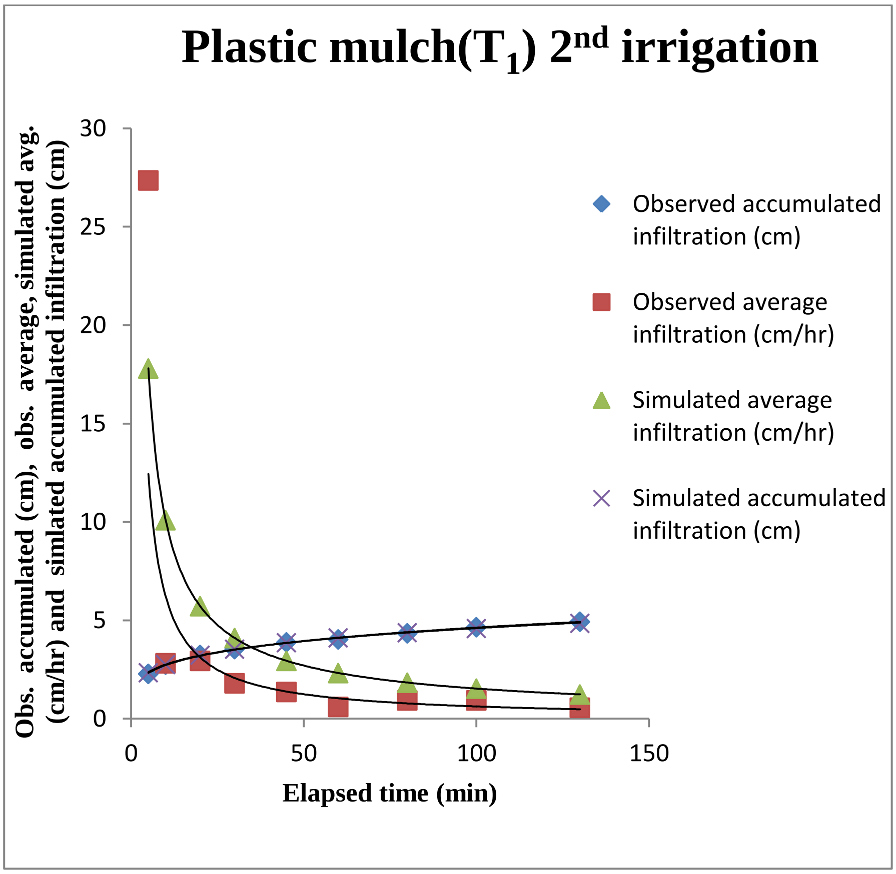

Plastic mulch ($T_1$) 1st irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration(cm)

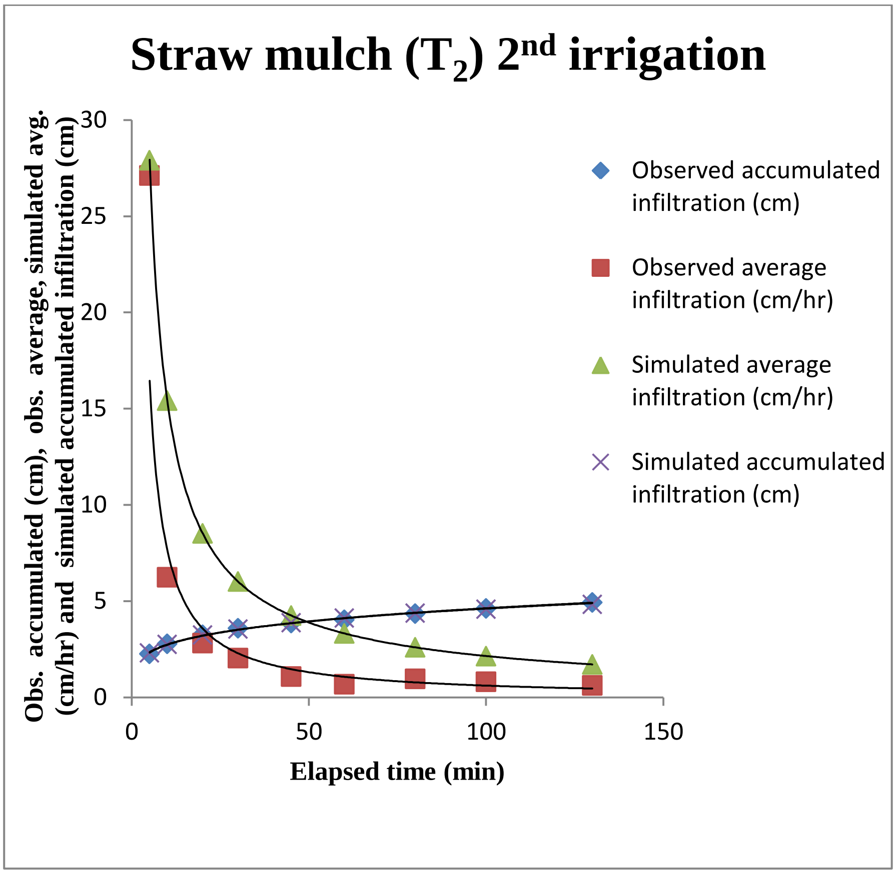

Straw mulch($T_2$) 1st irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
35
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration (cm)

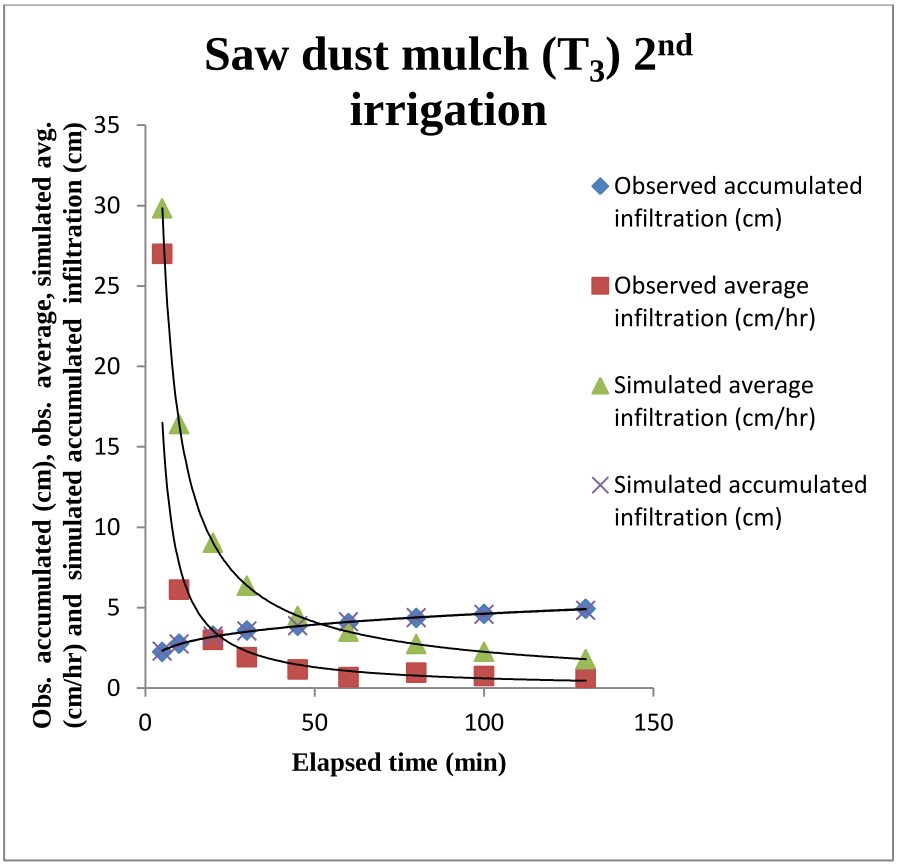

Saw dust mulch ($T_3$) 1st irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
0
5
10
15
20
25
30
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)

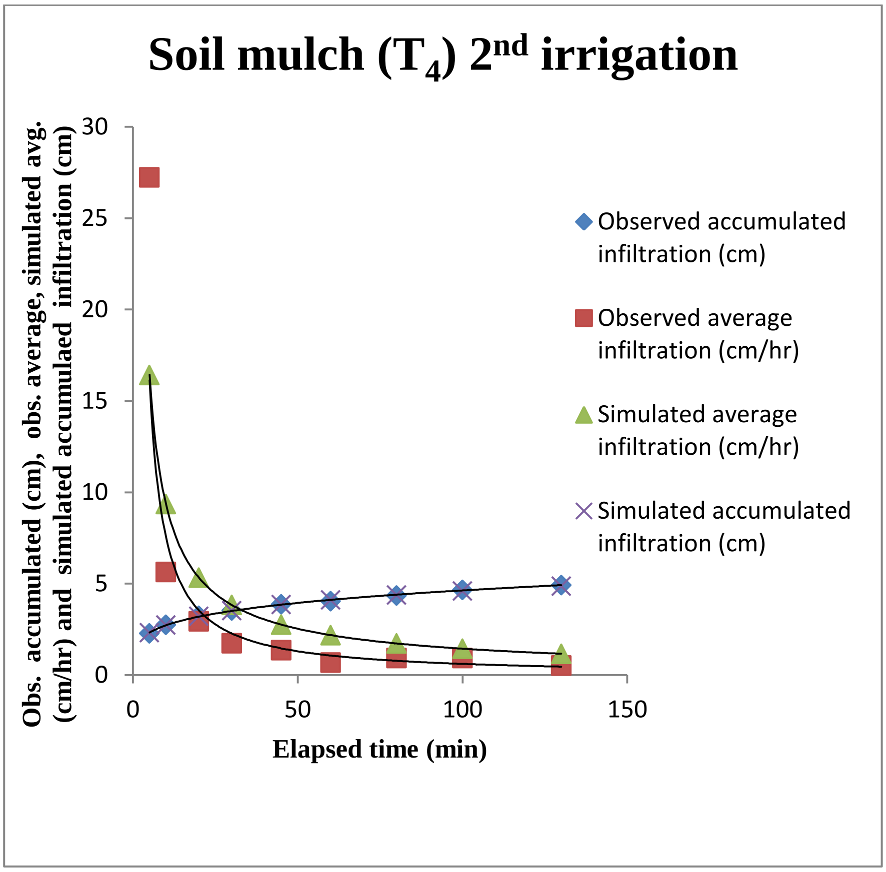

Soil mulch ($T_4$) 1st irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
0
5
10
15
20
25
30
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)

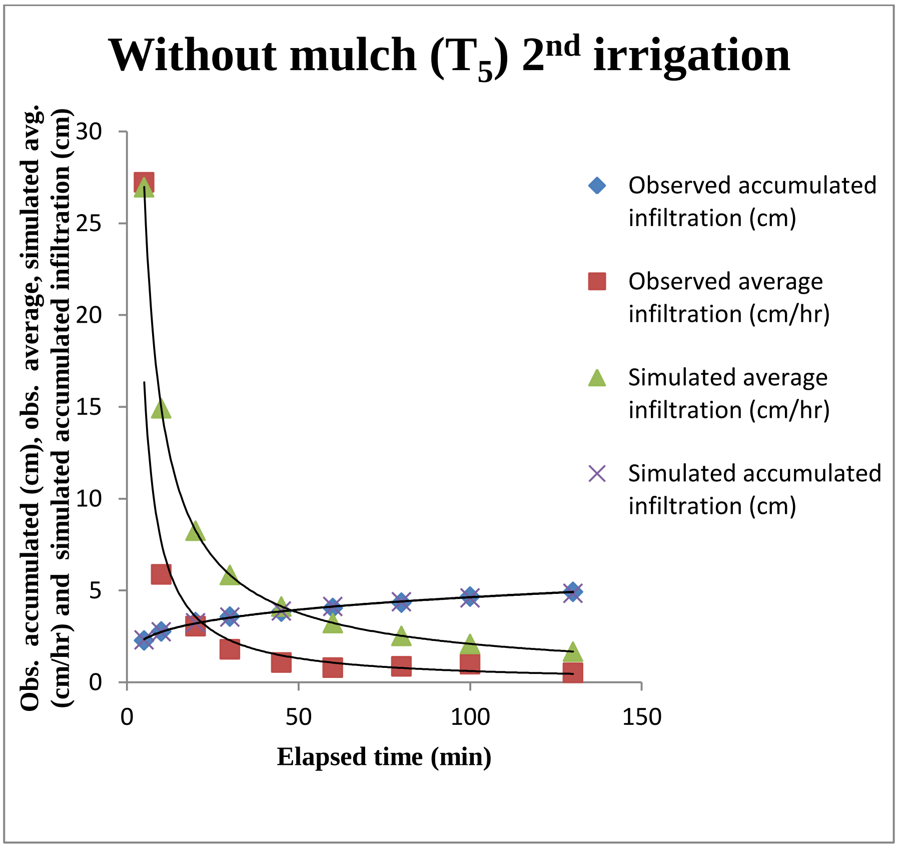

Without mulch (T$_5$) 1st irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
0
5
10
15
20
25
30
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration (cm)

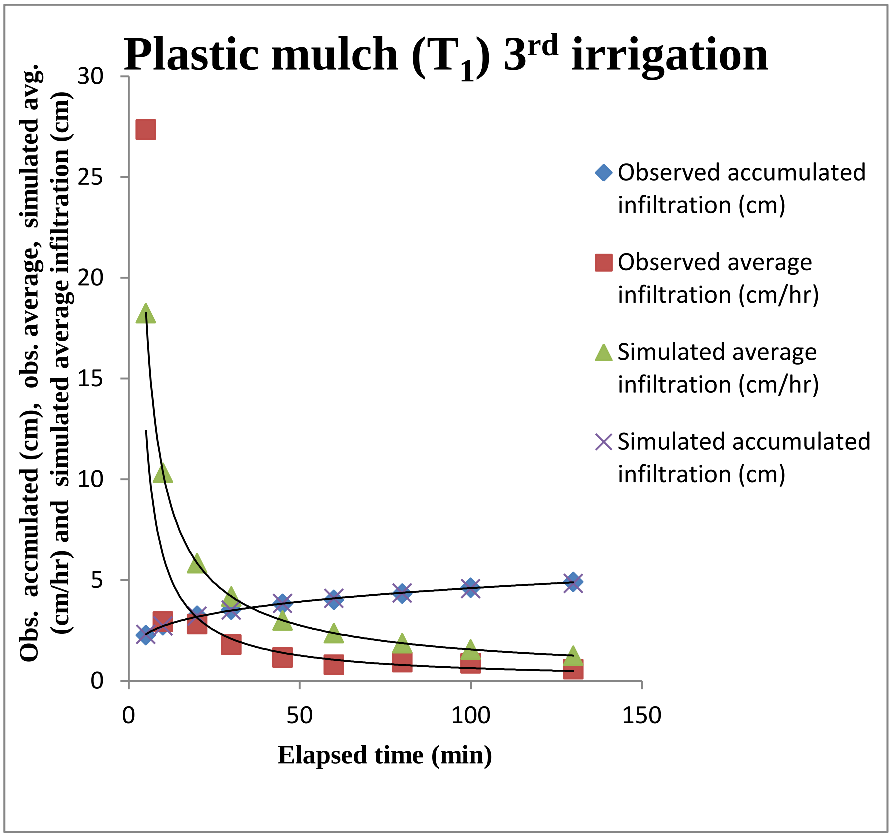

Plastic mulch(T$_1$) 2nd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simlated accumulated infiltration (cm)
0
5
10
15
20
25
30
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration (cm)

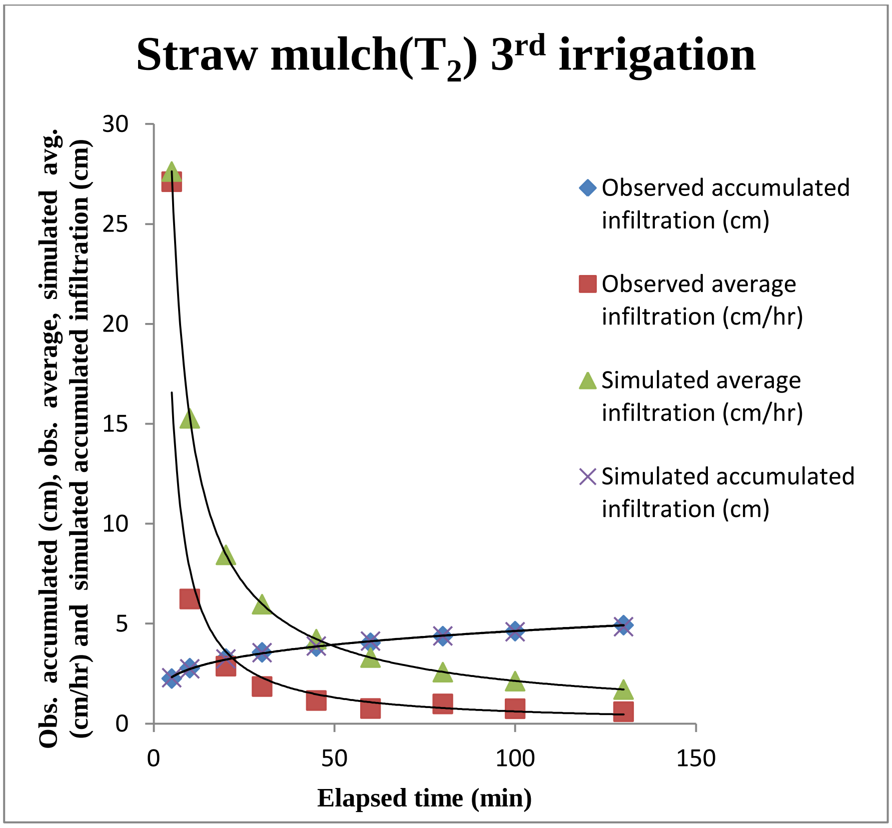

Straw mulch ($T_2$) 2nd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)

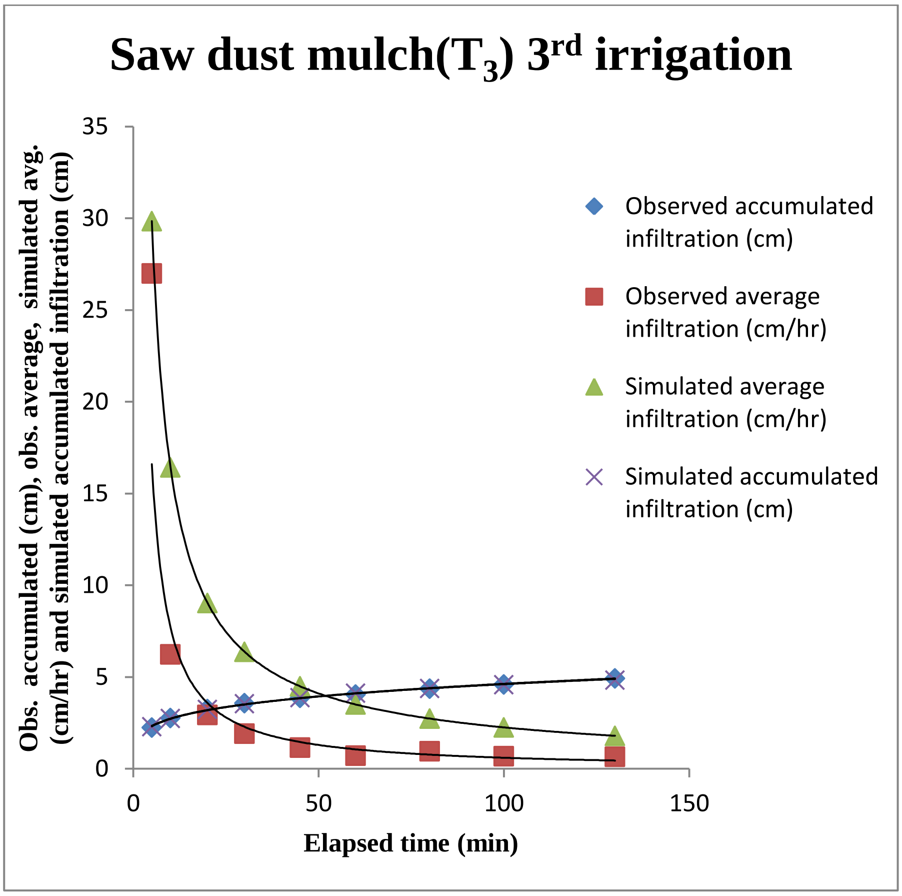

Saw dust mulch ($T_3$) 2nd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
35
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)

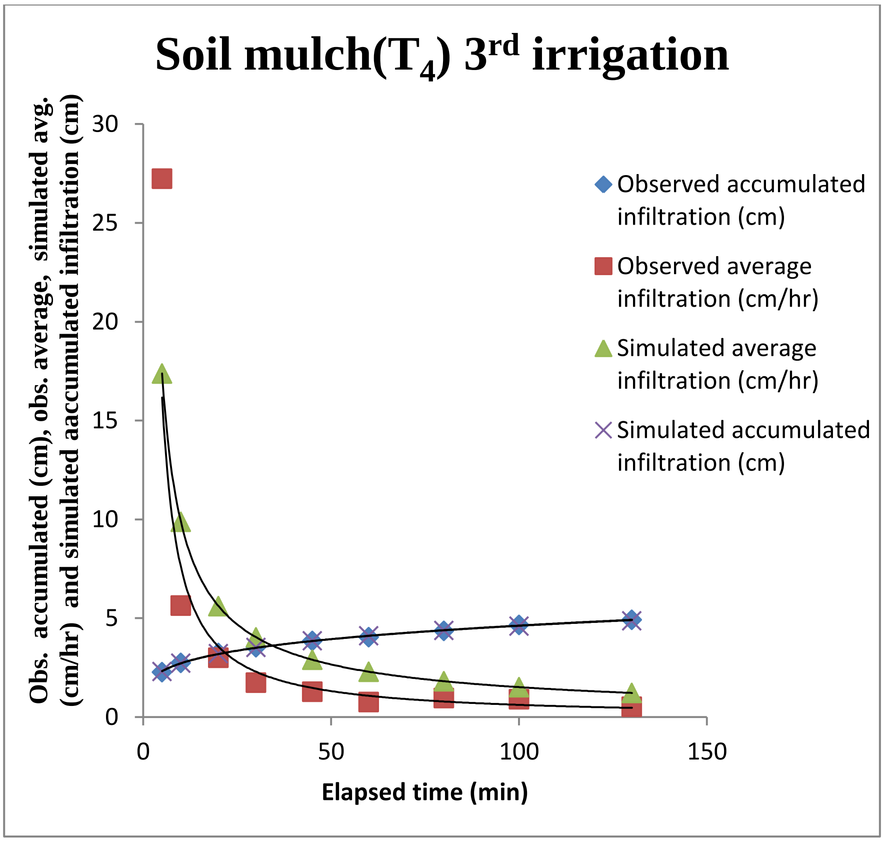

Soil mulch (T4) 2nd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulaed infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)


Without mulch (T5) 2nd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)


Plastic mulch ($T_1$) 3rd irrigation
Obs. accmulated (cm), obs. average, simulated avg. (cm/hr) and simulated average infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration (cm)


Straw mulch($T_2$) 3rd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
◆ Observed accumulated infiltration (cm)
■ Observed average infiltration (cm/hr)
▲ Simulated average infiltration (cm/hr)
× Simulated accumulated infiltration (cm)


Saw dust mulch($T_3$) 3rd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated accumulated infiltration (cm)
35
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)


Soil mulch($T_4$) 3rd irrigation
Obs. accumulated (cm), obs. average, simulated avg. (cm/hr) and simulated aaccumulated infiltration (cm)
30
25
20
15
10
5
0
0
50
100
150
Elapsed time (min)
Observed accumulated infiltration (cm)
Observed average infiltration (cm/hr)
Simulated average infiltration (cm/hr)
Simulated accumulated infiltration (cm)

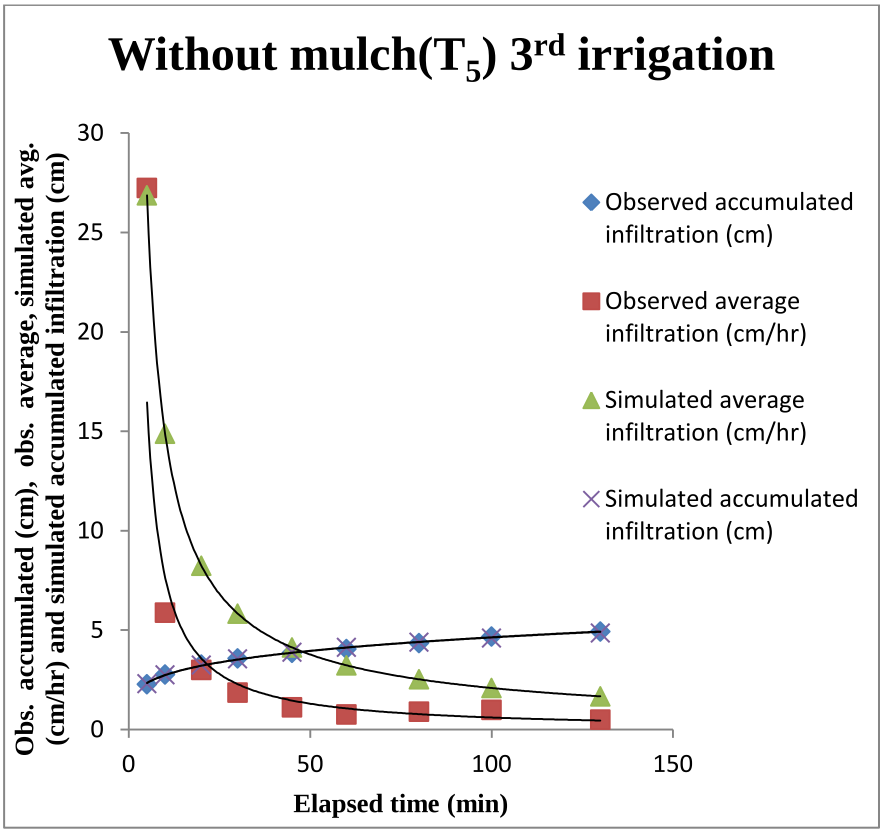
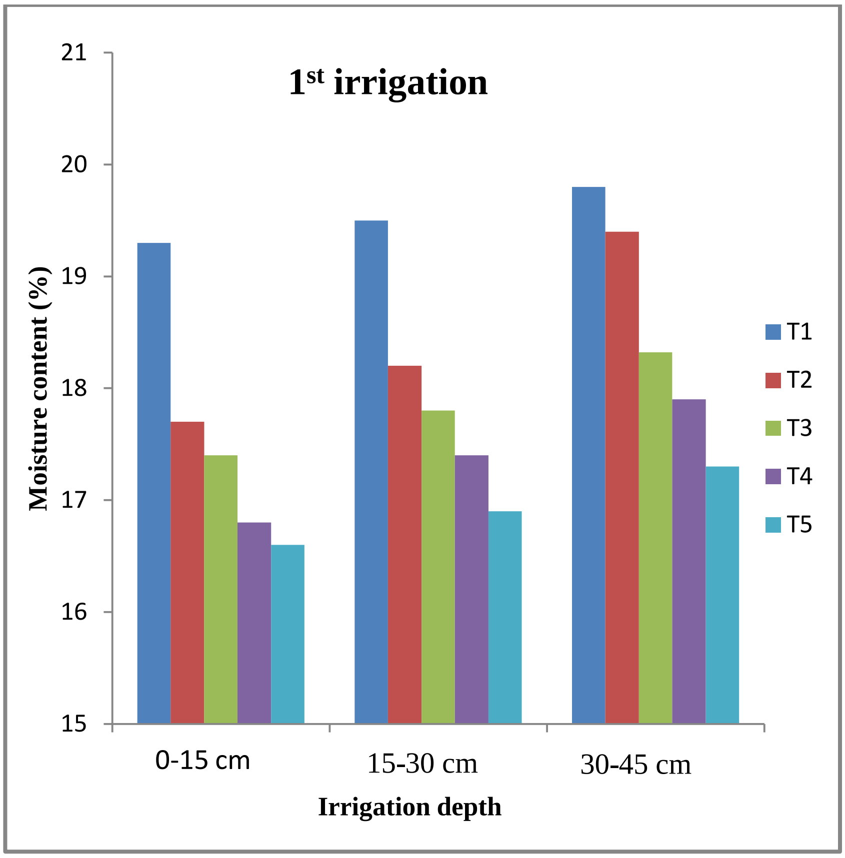
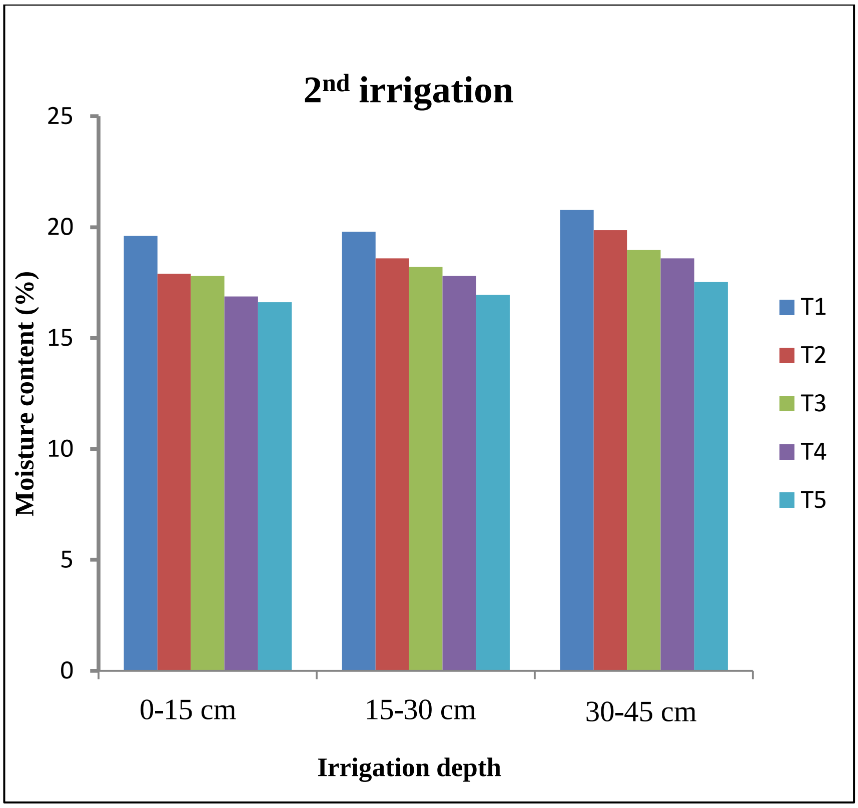


Fig. 4.5 Observed accumulated, observed average, simulated average and simulated accumulated infiltration v/s time

## 4.2 Soil Moisture Content

Soil moisture contents after first, second and third irrigation in furrow irrigated bed system were determined for each treatment which are given in Appendix-D and shown (Fig. 4.6). The data indicate that the moisture content was the highest in black plastic mulch and minimum in without mulch. In other words, soil moisture conservation in furrow irrigated raised bed with plastic mulch was more compared to other mulching treatments which shows the superiority of plastic mulch over other mulches used in the experiment. Because of this the vigour of brinjal crop was more resulting in much higher yield and fruit quality.


1st irrigation
Moisture content (%)
21
20
19
18
17
16
15
0-15 cm
15-30 cm
30-45 cm
Irrigation depth
T1
T2
T3
T4
T5


2nd irrigation
Moisture content (%)
25
20
15
10
5
0
0-15 cm
15-30 cm
30-45 cm
Irrigation depth
T1
T2
T3
T4
T5

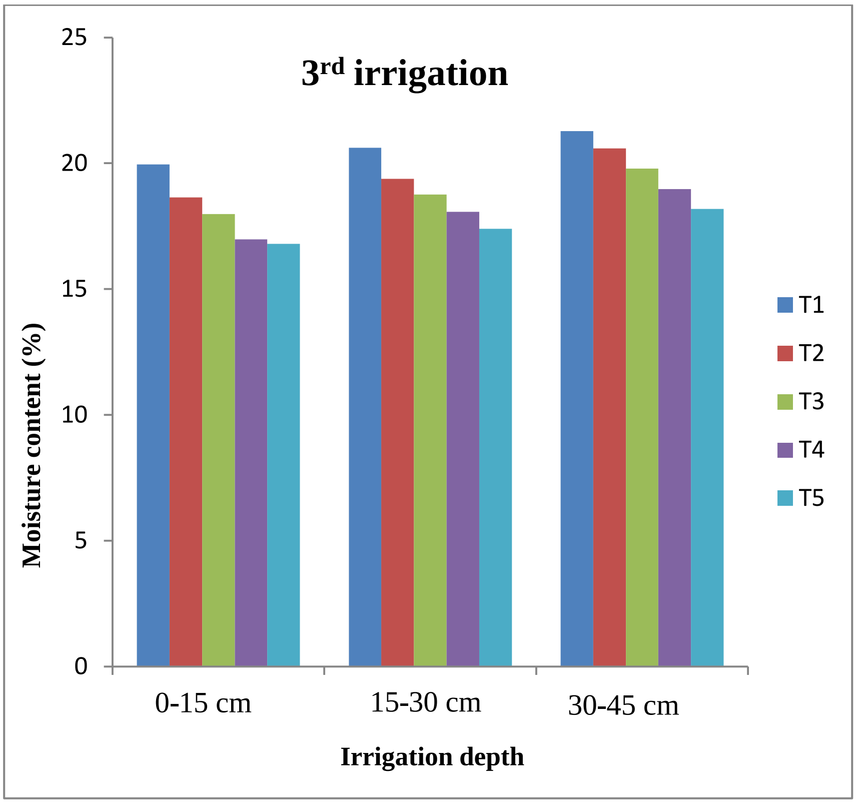


Fig. 4.6 Moisture content in different treatment at 1st, 2nd and 3rd irrigation

## 4.3 Irrigation Efficiencies

Various irrigation efficiencies are the important and real indicators of the hydraulic performance of an irrigation system. Water application, Water distribution, and water storage efficiencies were calculated at each irrigation during 2014-2015 of experimentation in each treatment. These efficiencies are discussed in following sectors.

### 4.3.1 Water Application Efficiency

The mean water application efficiency of furrow irrigated raised bed system in each treatment was computed and the results are given in Table 4.7 below and pictorial representation of the application efficiency for 1st, 2nd and 3rd irrigation in each treatment is shown in Fig. 4.7. It can be seen from the figure that black plastic mulch ($T_1$) resulted in maximum application efficiency in each irrigation. The application efficiency in the treatment $T_1$ was distinctly much higher in comparison to other treatments. The lowest application efficiency was found in $T_5$ i.e. furrow irrigated raised bed without any mulch. In treatment $T_2$ i.e. straw mulch, the application efficiency was found to be higher (about 73 to 81%) during 1st, 2nd and 3rd irrigation. Hence, if the objectives only water saving, the $T_2$ treatment may also be considered as an efficient irrigation system after plastic mulch treatment.

Table 4.7 Application Efficiency under 1st, 2nd and 3rd irrigation in different treatments

| Treatment | Water application efficiency (%) | | | | |
|---|---|---|---|---|---|
| | 1st irrigation | 2nd irrigation | 3rd irrigation | Average (%) | % increase as compared to control ($T_5$) |
| $T_1$ | 78.78 | 82.43 | 84.68 | 81.96 | 25.58 |
| $T_2$ | 73.38 | 75.22 | 80.81 | 76.47 | 17.16 |
| $T_3$ | 68.33 | 72.68 | 76.87 | 72.62 | 11.27 |
| $T_4$ | 66.55 | 69.66 | 70.39 | 68.86 | 5.51 |
| $T_5$ | 63.53 | 64.64 | 67.63 | 65.26 | - |

Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).

Observing Table 4.7, it is found that the maximum (25.58%) saving of water in irrigation application occurred in treatment $T_1$ (Plastic mulch) followed by treatment $T_2$ (Straw mulch) in comparison to treatment $T_5$ (Without mulch). In treatment $T_3$ (Saw dust mulch) and treatment $T_4$ (Soil mulch), the water saving was not much significant.

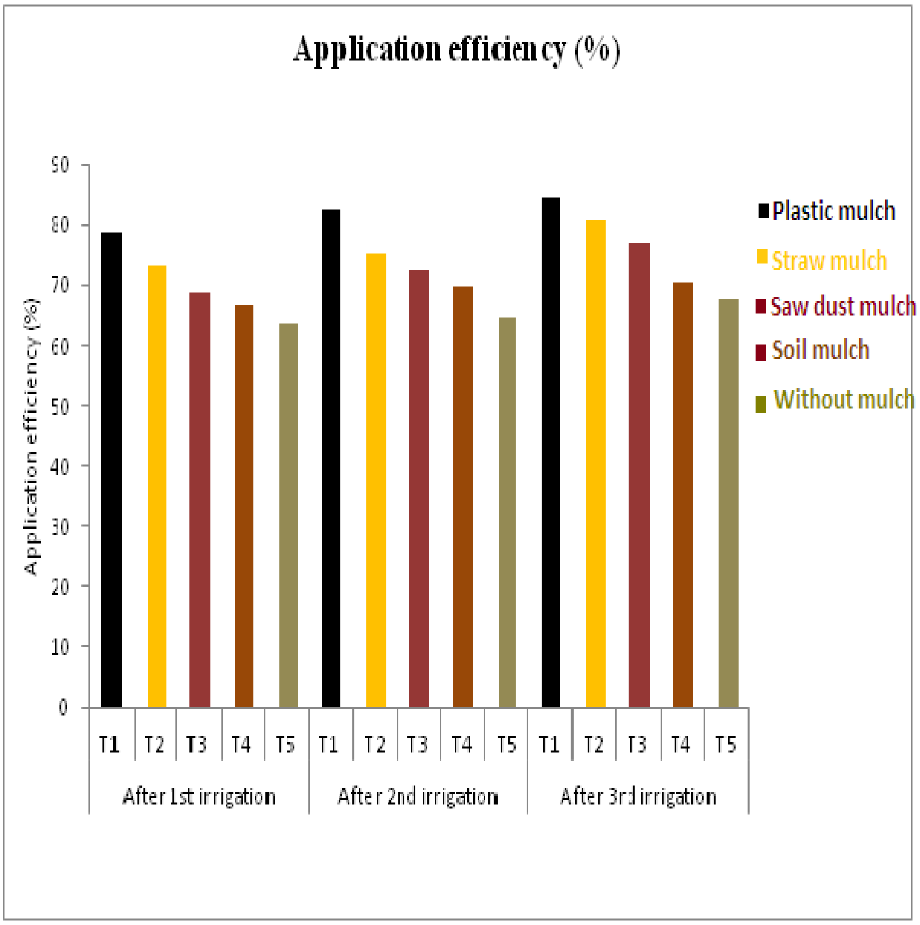


Fig. 4.7 Mean water application efficiency under various irrigation systems

### 4.3.2 Water Distribution Efficiency

The mean water distribution efficiency in each treatment was also computed and which are given in Table 4.8 below. Distribution efficiencies of each treatment are also shown in Fig.4.8. It is clear from Fig.4.5 that distribution efficiency was also indicating the same trend as that of application efficiency.

Table 4.8 Distribution efficiency under 1st, 2nd and 3rd irrigation in different treatments

| Treatment | Water distribution efficiency (%) | | | | |
|---|---|---|---|---|---|
| | 1st irrigation | 2nd irrigation | 3rd irrigation | Average (%) | % increase as compared to control ($T_5$) |
| $T_1$ | 86.02 | 89.98 | 91.37 | 89.12 | 16.7 |
| $T_2$ | 83.83 | 85.78 | 89.64 | 86.41 | 13.1 |
| $T_3$ | 80.61 | 82.75 | 86.62 | 83.32 | 9.1 |
| $T_4$ | 78.38 | 80.79 | 84.45 | 81.20 | 6.3 |
| $T_5$ | 71.10 | 77.86 | 80.18 | 76.38 | - |

Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).

If the average distribution efficiency is considered, it is evident from Table 4.8 that the highest average distribution efficiency (89.12%) also found in treatment $T_1$ (Plastic mulch) and there was a decreasing trend in the distribution efficiency in treatments $T_2$ (Straw mulch), $T_3$ (Saw dust mulch), $T_4$ (Soil mulch), and $T_5$ (Without mulch) respectively. As regards saving of irrigation water, it is seen (Table 4.8) that as compared to $T_5$ (Without mulch), there was about 16.7% water saving in $T_1$ (Plastic mulch) and about 13.1% water was saved in $T_2$ (Straw mulch) in comparison to $T_5$ (Without mulch). In $T_3$ (Saw dust mulch) and $T_4$ (Soil mulch), only about 6.3% to 9.1% water was saved which is not much significant saving as compared to $T_5$ (Without mulch). In other words, the $T_1$ (Plastic mulch) and $T_2$ (Straw mulch) resulted in higher water saving due to less evaporation losses as compared to other treatments.

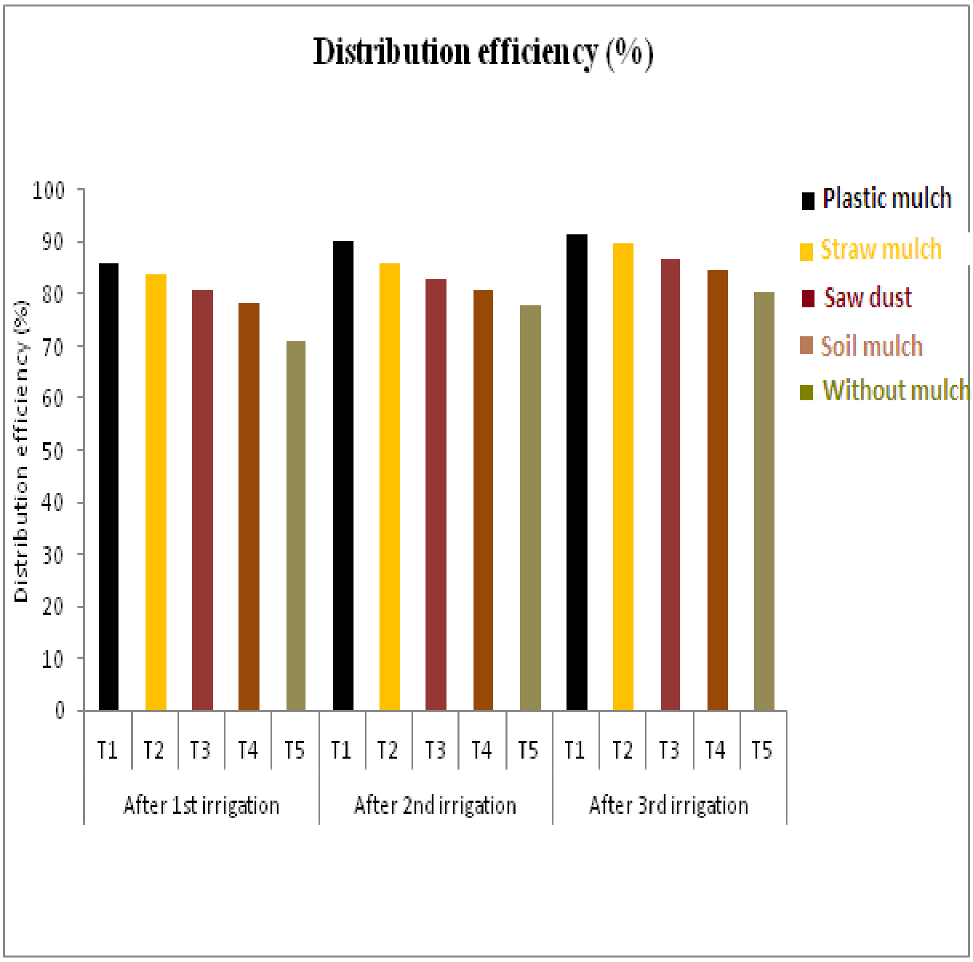


Fig.4.8 Mean water distribution efficiency under various irrigation systems

### 4.3.3 Water Use Efficiency

### 4.3.3.1 Field Water-Use Efficiency

In the study, field water use efficiency was determined at each irrigation for each treatment as given in Table 4.9 and shown in Fig.4.9. In line with application and distribution efficiencies, the field water-use efficiency of furrow irrigation raised bed system with plastic mulch ($T_1$) was found to be highest (64.1 q/ha-cm) followed by treatment $T_2$ (50.1 q/ha-cm) and the lowest field water-use efficiency was obtained in treatment $T_5$ (without mulch).

Table 4.9 Field water-use efficiency under different treatments

| Particular | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
|---|---|---|---|---|---|
| Field water use efficiency (q/ha-cm) | 64.1 | 50.1 | 48.94 | 48.38 | 47.47 |
| % increase as compared to control ($T_5$) | 35.0 | 5.5 | 3.1 | 1.9 | - |

Note: $T_1$=Plastic mulch, $T_2$=Straw mulch, $T_3$=Saw dust mulch, $T_4$=Soil mulch, $T_5$=Without mulch (Control).

It is quite evident from Table 4.9 that there was very significant increase (35%) in water use efficiency in case of treatment $T_1$ (Plastic mulch) in comparison to $T_5$ (Without mulch). Increase of water use efficiency in other treatments was not much significant.

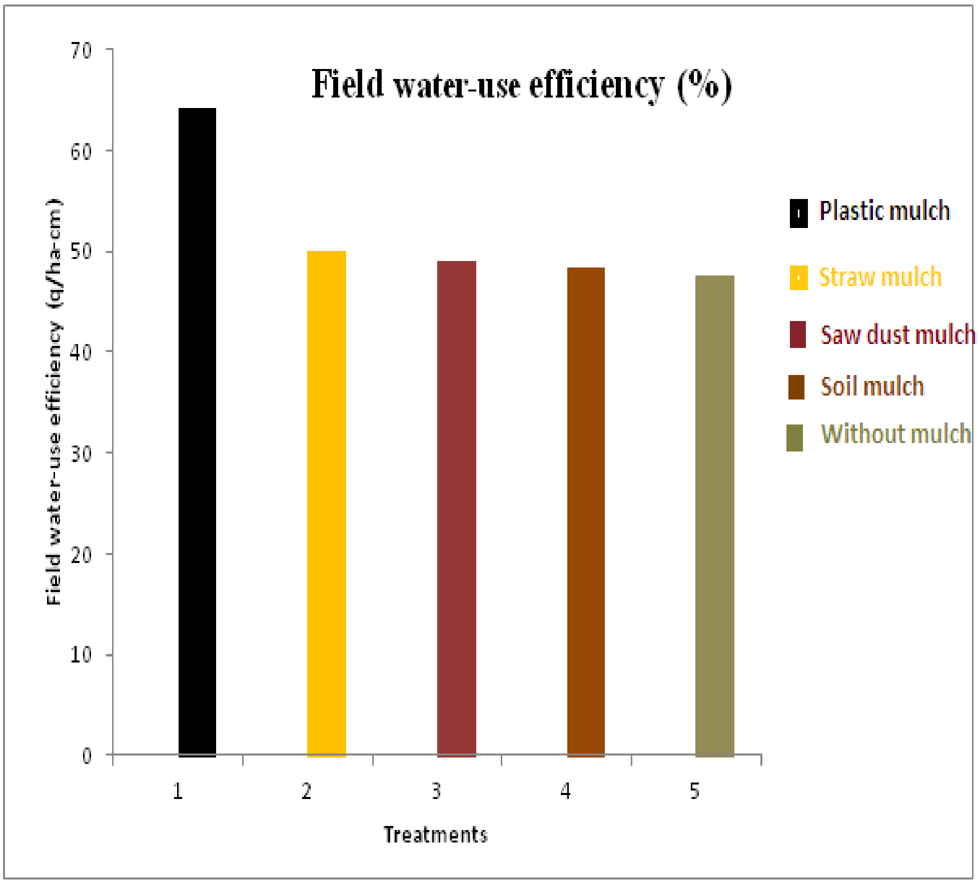


Fig.4.9 Field water-use efficiency under different treatments

### 4.3.4 Economics

Gross cost of cultivation of *brinjal* under different treatments was determined using actual expenditure incurred on various agricultural inputs used, field preparation, fertilizer and manure application, *brinjal* seedlings, insecticide and pesticide which were common for all treatments. These costs were converted to cost per hectare which were found to be Rs. 19535.53, 6095.238, 6827.839, 9142.857 and 2147.985, respectively. The cost of mulching materials was also determined separately for each treatment that varied from Rs. 10256.41 (saw dust mulch) to Rs. 16000`00 (plastic mulch).The cost of straw was not included in the analysis as it was obtained free of cost from the horticulture department of the college of Agriculture, Raipur. Labour cost was also variable ranging from Rs. 13919.41 to 18315.02 (Table 4.10). After adding all costs, the gross cost of cultivation was determined as Rs. 78064.47 ($T_1$), Rs. 61038.83 ($T_2$), Rs. 68950.92 ($T_3$), Rs. 57668.86 ($T_4$) and Rs. 55471.06. It is evident that the total cost of cultivation was highest in treatment$T_1$ due to relatively higher cost of plastic mulch. The lowest cultivation cost was found in treatment $T_5$ as no mulching cost was involved and the labour requirement was also lowest.

The gross benefit from each of the treatments was determined based on the selling price of the *brinjal* in the market prevailing in the year 2014-15. As the yield of *brinjal* in treatment $T_1$ was found to be the highest, obviously the gross benefit also was highest in treatment $T_1$ (Rs. 301490.00). The gross benefit (Rs. 68950.92) from treatment $T_3$ was also quite high but the lowest benefit (Rs. 55471.06) occurred in treatment $T_5$. Based on gross benefit and gross cost of cultivation, benefit-cost ratios were determined for all the treatments. The B/C ratios were found to be 3.86 ($T_1$), 3.53 ($T_2$), 3.38 ($T_3$), 3.48 ($T_4$) and 3.43 ($T_5$). This clearly indicates that the furrow irrigation with plastic mulching results in the maximum profit per unit investment cost and furrow irrigation with no mulching gives the lowest profit per unit investment cost.

Table 4.10 Gross cost of cultivation of *brinjal* (converted to Rs./ ha) under different treatments

| Particular | Treatment | | | | |
|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| Field preparation | 19535.53 | 19535.53 | 19535.53 | 19535.53 | 19535.53 |
| Fertilizer cost | 6095.23 | 6095.23 | 6095.23 | 6095.23 | 6095.23 |
| Manure cost | 6827.83 | 6827.83 | 6827.83 | 6827.83 | 6827.83 |
| Nursery cost | 9142.85 | 9142.85 | 9142.85 | 9142.85 | 9142.85 |
| Insecticide | 2147.98 | 2147.98 | 2147.98 | 2147.98 | 2147.98 |
| Plastic mulch | 16000.00 | | | | |
| Saw dust mulch | | | 10256.41 | | |
| Labour cost | 18315.02 | 17289.38 | 14945.05 | 13919.41 | 11721.61 |
| Total = | 78064.47 | 61038.83 | 68950.92 | 57668.86 | 55471.06 |

Table 4.11 Gross profit from cultivation of *brinjal* (converted to Rs./ha) and benefit-cost ratio under different treatments

| Particular | Treatments | | | | |
|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| Total yield of Brinjal (q)/ha | 448.70 | 350.70 | 342.60 | 338.70 | 332.30 |
| Marketable yield (q)/ha | 430.70 | 308.60 | 333.40 | 286.90 | 272.40 |
| Selling price @ Rs./q | 700.00 | 700.00 | 700.00 | 700.00 | 700.00 |
| Gross profit from marketable yield, Rs. | 301490.00 | 216020.00 | 233380.00 | 200830.00 | 190680.00 |
| Gross cost of cultivation, Rs. | 78064.47 | 61038.83 | 68950.92 | 57668.86 | 55471.06 |
| Benefit cost ratio | 3.86 | 3.53 | 3.38 | 3.48 | 3.43 |

## CHAPTER-V

# SUMMARY AND CONCLUSIONS

Irrigation is the biggest consumer of water. Therefore, water saving techniques without compromising on yield need to be studied and demonstrated to farmers for ensuring national food security by matching the actual crop water demand and supply.

Therefore, with a view to have an efficient and economically viable method for irrigating brinjal crop, a field study on “Performance Evaluation of Furrow Irrigation System for Brinjal with Different Mulches Material” was conducted at Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The aim of the experiment was to study the hydraulic performance of furrow irrigation system, to find out effect of mulches on soil moisture content, soil moisture depletion, infiltration characteristics, and irrigation efficiencies, time of waterfront advance and recession and yield of *brinjal* and to work out economics of furrow irrigation system for production of brinjal with different type of mulches. The soil of the study area was clay loam. Under the experiment, four types of mulches viz. plastic sheet, paddy straw, saw dust and soil mulch were used in furrow irrigated brinjal.

In the study, prediction models for time of waterfront advance and recession were developed. The relations of time of advance and recession were found to be of power equation and the predicted values matched closely to the observed values.

The basic infiltration rate of experimental soil under three irrigation, during each treatment was found to be 0.44, 0.62, 0.6, 0.48 and 0.46 ($1^{st}$ irrigation), 0.56, 0.62, 0.64, 0.52 and 0.52 ($2^{nd}$ irrigation), 0.58,0.6,0.66, 0.52 and 0.5 ($3^{rd}$ irrigation, $T_3$)

Soil moisture content after $1^{st}$, $2^{nd}$ and $3^{rd}$ irrigation in each treatment was found to be the highest in black plastic mulch and minimum in without mulch. Soil moisture conservation in furrow irrigation with plastic mulch was compared with other mulching treatments, which showed the superiority of plastic mulch over other mulches used in the experiment.

The application efficiency in the treatment $T_1$ (furrow irrigation with plastic mulch) was distinctly much higher in comparison to other treatments. The lowest application efficiency was found in $T_5$ i.e. furrow irrigation without any mulch. In treatment $T_2$ i.e. straw mulch, the application efficiency was found to be higher (about 73 to 81%) during 1st, 2nd and 3rd irrigation which were still on higher side. Hence, if the objective is only water saving, the $T_2$ treatment may also be considered as an efficient irrigation system after plastic mulch treatment. Distribution efficiency was also high indicating the same trend as that of application efficiency.

The field water-use efficiency of furrow irrigation system with plastic mulch ($T_1$) was found to be highest (64.1 q/ha-cm) followed by treatment $T_2$ (50.1 q/ha-cm) and the lowest field water-use efficiency was obtained in treatment $T_5$ (without mulch).

In the study the economic analysis was also made for all the treatments. The gross cost of cultivation was determined as Rs. 78064.47 ($T_1$) Rs. 61038.83 ($T_2$), Rs. 68950.92 ($T_3$), Rs. 57668.86 ($T_4$) and Rs. 55471.06. The total cost of cultivation was highest in treatment$T_1$ due to relatively higher cost of plastic mulch. The lowest cultivation cost was found in treatment $T_5$ as no mulching cost was involved and the labour requirement was also lowest.

The gross benefit from each of the treatments was determined based on the selling price of the *brinjal* in the market prevailing in the year 2014-15. The yield of *brinjal* in treatment $T_1$ was found to be the highest, obviously the gross benefit also was highest in treatment $T_1$ (Rs. 301490.00). Based on gross benefit and gross cost of cultivation, benefit-cost ratios were determined for all the treatments. The B/C ratios were found to be 3.86 ($T_1$), 3.53 ($T_2$), 3.38 ($T_3$), 3.48 ($T_4$) and 3.43 ($T_5$). This clearly indicates that the furrow irrigation with plastic mulching results in the maximum profit per unit investment cost and furrow irrigation with no mulching gives the lowest profit per unit investment cost.

The present study led to the following conclusions:

1. In hydraulic evaluation of furrow irrigation system, the basic infiltration rate in treatment $T_1$ (black plastic mulch) was attained after relatively longer time indicating that the escape of the moisture was minimum in $T_1$ due to polythene sheets. Mulching by polythene sheet resulted in higher moisture storage in soil profile as compared to other mulching material. This shows that more soil moisture conservation in furrow irrigated raised bed is obtained with plastic mulch.
2. The closeness of observed infiltration rates and infiltration rates predicted by modified Kostiakov equation showed that Kostiakov equation fits well to infiltration rate of the soil of the study area.
3. The time of waterfront advance and recession in furrows is best described by the equation of power form in the study area giving the highest coefficient of determination ($R^2$) in all the treatments.
4. The waterfront advance and recession curves were almost parallel which indicates that the distribution of irrigation water at different points along the furrows was quite uniform, thus furrow irrigation results in higher distribution efficiency.
5. Furrow irrigation with black plastic mulch gives high irrigation application efficiency as well as water-use efficiency compared to other mulching materials used in the study.
6. Furrow irrigation with black plastic mulch results in higher net returns from *brinjal* under prevailing field conditions of the study area.

## SUGGESTION FOR FUTURE WORK:

1. Similar type of experiment can be conducted in different soil types.
2. Experiment can be conducted on other mulching materials (dry leafs, waste plastic bag etc.).
3. Experiments can be conducted in furrow irrigated raised bed system with cereal crops and as well as other vegetables.

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## APPENDIX –A

Table A1: Advance and recession time for furrow irrigation system at 1st, 2nd and 3rd irrigation

**Treatment -1**

| After 1st irrigation | | | After 2nd irrigation | | | After 3rd irrigation | | |
|---|---|---|---|---|---|---|---|---|
| Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) |
| 0 | 0.00 | 33.25 | 0 | 0.00 | 34 | 0 | 0.00 | 34.33 |
| 5 | 1.10 | 36.16 | 5 | 2.50 | 36.6 | 5 | 2.50 | 36.98 |
| 10 | 1.80 | 38.98 | 10 | 4.00 | 38.87 | 10 | 3.00 | 37 |
| 15 | 2.19 | 41.5 | 15 | 5.25 | 41.9 | 15 | 4.16 | 42.2 |
| 20 | 3.03 | 43.98 | 20 | 7.00 | 44.4 | 20 | 6.75 | 44.2 |
| 25 | 5.19 | 46.25 | 25 | 8.50 | 46.75 | 25 | 8.33 | 46.86 |
| 30 | 7.48 | 47.96 | 30 | 10.00 | 48.2 | 30 | 11.60 | 48.7 |
| 35 | 8.25 | 49.44 | 35 | 11.50 | 49.97 | 35 | 13.16 | 50.1 |

Table A2: Advance and recession time for furrow irrigation system at 1st, 2nd and 3rd irrigation

**Treatment -2**

| After 1st irrigation | | | After 2nd irrigation | | | After 3rd irrigation | | |
|---|---|---|---|---|---|---|---|---|
| Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) |
| 0 | 0.00 | 34.76 | 0 | 0.00 | 33.22 | 0 | 0.00 | 34.98 |
| 5 | 2.08 | 37.4 | 5 | 2.58 | 36.5 | 5 | 2.70 | 37.55 |
| 10 | 3.00 | 38.55 | 10 | 4.25 | 37.8 | 10 | 4.96 | 38.3 |
| 15 | 4.08 | 40.3 | 15 | 5.16 | 40 | 15 | 7.44 | 40.46 |
| 20 | 5.50 | 42.64 | 20 | 7.44 | 42.76 | 20 | 9.58 | 43 |
| 25 | 7.75 | 45.25 | 25 | 10.08 | 44.25 | 25 | 12.66 | 45.33 |
| 30 | 10.00 | 47 | 30 | 10.00 | 47.3 | 30 | 14.16 | 47.8 |
| 35 | 12.16 | 49.23 | 35 | 13.16 | 49.6 | 35 | 17.16 | 53 |

Table A3: Advance and recession time for furrow irrigation system at 1st, 2nd and 3rd irrigation

**Treatment** -3

| After 1st irrigation | | | After 2nd irrigation | | | After 3rd irrigation | | |
|---|---|---|---|---|---|---|---|---|
| Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) |
| 0 | 0.00 | 33.4 | 0 | 0.00 | 34 | 0 | 0.00 | 34.87 |
| 5 | 2.25 | 36.6 | 5 | 2.66 | 36.72 | 5 | 3.00 | 37.44 |
| 10 | 3.50 | 37 | 10 | 4.14 | 38.54 | 10 | 4.83 | 38.2 |
| 15 | 5.18 | 40.45 | 15 | 8.66 | 41 | 15 | 6.50 | 40.36 |
| 20 | 7.00 | 42.77 | 20 | 11.16 | 42.65 | 20 | 9.75 | 43.2 |
| 25 | 9.16 | 45.68 | 25 | 12.25 | 45.3 | 25 | 12.33 | 45.22 |
| 30 | 12.00 | 47.45 | 30 | 14.33 | 47.76 | 30 | 15.16 | 47.7 |
| 35 | 14.25 | 49.87 | 35 | 17.16 | 49 | 35 | 17.66 | 50.1 |

Table A4: Advance and recession time for furrow irrigation system at 1st, 2nd and 3rd irrigation

**Treatment -4**

| After 1st irrigation | | | After 2nd irrigation | | | After 3rd irrigation | | |
|---|---|---|---|---|---|---|---|---|
| Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) |
| 0 | 0.00 | 34.88 | 0 | 0.00 | 33 | 0 | 0.00 | 34.3 |
| 5 | 2.00 | 37.3 | 5 | 2.50 | 36.7 | 5 | 2.50 | 37.9 |
| 10 | 2.50 | 38.6 | 10 | 4.00 | 37.45 | 10 | 3.00 | 38.1 |
| 15 | 3.16 | 40.3 | 15 | 5.25 | 40 | 15 | 4.16 | 40.21 |
| 20 | 4.00 | 43.22 | 20 | 7.00 | 42.22 | 20 | 6.75 | 43.11 |
| 25 | 6.16 | 45.5 | 25 | 8.50 | 45.8 | 25 | 8.33 | 45 |
| 30 | 8.45 | 47.19 | 30 | 10.00 | 47.53 | 30 | 11.60 | 47.66 |
| 35 | 9.25 | 49.8 | 35 | 11.50 | 50 | 35 | 13.16 | 49.5 |

Table A5: Advance and recession time for furrow irrigation system at 1st, 2nd and 3rd irrigation

**Treatment -5**

| After 1st irrigation | | | After 2nd irrigation | | | After 3rd irrigation | | |
|---|---|---|---|---|---|---|---|---|
| Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) | Advance distance (m) | Advance time (min) | Recession time (min) |
| 0 | 0.00 | 34.1 | 0 | 0.00 | 33.8 | 0 | 0.00 | 34 |
| 5 | 2.00 | 37.45 | 5 | 2.50 | 36.43 | 5 | 2.50 | 37.7 |
| 10 | 2.50 | 38.8 | 10 | 4.00 | 37.59 | 10 | 3.00 | 38.54 |
| 15 | 3.16 | 40.32 | 15 | 5.25 | 40.78 | 15 | 4.16 | 40.33 |
| 20 | 4.00 | 43.65 | 20 | 7.00 | 42.44 | 20 | 6.75 | 43.4 |
| 25 | 6.16 | 45.86 | 25 | 8.50 | 45.7 | 25 | 8.33 | 45.76 |
| 30 | 8.45 | 47.57 | 30 | 10.00 | 47.97 | 30 | 11.60 | 47 |
| 35 | 9.25 | 49.48 | 35 | 11.50 | 49.7 | 35 | 13.16 | 48.95 |

## APPENDIX - B

Table B1: Measurement furrow infiltration at 1st, 2nd and 3rd irrigation by volume balance method and computation of accumulated and average infiltration

**Treatment 1**

| After 1st irrigation | | | | | | After 2nd irrigation | | | | | | After 3rd irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. Avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. Avg. infilt. (cm/h) | Simulated avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. Avg. infilt. (cm/h) | Simulated avg. infilt. (cm/h) |
| 5 | 2.27 | 2.27 | 2.31 | 27.24 | 21.04 | 5 | 2.28 | 2.28 | 2.32 | 27.36 | 17.8 | 5 | 2.28 | 2.27 | 2.31 | 27.36 | 18.25 |
| 10 | 0.49 | 2.76 | 2.74 | 2.94 | 11.82 | 10 | 0.47 | 2.75 | 2.75 | 2.82 | 10.09 | 10 | 0.49 | 2.76 | 2.73 | 2.94 | 10.33 |
| 20 | 0.47 | 3.23 | 3.22 | 2.82 | 6.64 | 20 | 0.49 | 3.24 | 3.23 | 2.94 | 5.72 | 20 | 0.47 | 3.23 | 3.21 | 2.82 | 5.84 |
| 30 | 0.31 | 3.54 | 3.54 | 1.86 | 4.74 | 30 | 0.3 | 3.54 | 3.53 | 1.8 | 4.1 | 30 | 0.3 | 3.53 | 3.51 | 1.8 | 4.19 |
| 45 | 0.35 | 3.89 | 3.87 | 1.4 | 3.38 | 45 | 0.34 | 3.88 | 3.86 | 1.36 | 2.94 | 45 | 0.29 | 3.82 | 3.84 | 1.16 | 3 |
| 60 | 0.16 | 4.05 | 4.12 | 0.64 | 2.66 | 60 | 0.15 | 4.03 | 4.11 | 0.6 | 2.32 | 60 | 0.2 | 4.02 | 4.09 | 0.8 | 2.37 |
| 80 | 0.28 | 4.33 | 4.38 | 0.84 | 2.09 | 80 | 0.31 | 4.34 | 4.37 | 0.93 | 1.83 | 80 | 0.31 | 4.33 | 4.36 | 0.93 | 1.87 |
| 100 | 0.35 | 4.68 | 4.59 | 1.05 | 1.74 | 100 | 0.31 | 4.65 | 4.58 | 0.93 | 1.53 | 100 | 0.29 | 4.62 | 4.57 | 0.87 | 1.56 |
| 130 | 0.22 | 4.9 | 4.85 | 0.44 | 1.39 | 130 | 0.28 | 4.93 | 4.85 | 0.56 | 1.23 | 130 | 0.29 | 4.91 | 4.83 | 0.58 | 1.25 |

Table B2: Measurement furrow infiltration at 1st, 2nd and 3rd irrigation by volume balance method and computation of accumulated and average infiltration

**Treatment 2**

| After 1st irrigation | | | | | | After 2nd irrigation | | | | | | After 3rd irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infiltr. (cm) | Simulated accu. Infiltr. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration. depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infiltr. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) |
| 5 | 2.26 | 2.26 | 2.30 | 27.12 | 31.18 | 5 | 2.26 | 2.26 | 2.31 | 27.12 | 27.91 | 5 | 2.26 | 2.26 | 2.3 | 27.12 | 27.63 |
| 10 | 0.52 | 2.78 | 2.75 | 6.24 | 17.13 | 10 | 0.52 | 2.78 | 2.75 | 6.24 | 15.42 | 10 | 0.52 | 2.78 | 2.74 | 6.24 | 15.28 |
| 20 | 0.47 | 3.25 | 3.24 | 2.82 | 9.41 | 20 | 0.47 | 3.25 | 3.24 | 2.82 | 8.52 | 20 | 0.48 | 3.26 | 3.24 | 2.88 | 8.45 |
| 30 | 0.34 | 3.59 | 3.55 | 2.04 | 6.63 | 30 | 0.34 | 3.59 | 3.53 | 2.04 | 6.02 | 30 | 0.31 | 3.57 | 3.55 | 1.86 | 5.98 |
| 45 | 0.27 | 3.86 | 3.88 | 1.08 | 4.67 | 45 | 0.27 | 3.86 | 3.88 | 1.08 | 4.25 | 45 | 0.29 | 3.86 | 3.88 | 1.16 | 4.23 |
| 60 | 0.17 | 4.03 | 4.12 | 0.68 | 3.64 | 60 | 0.17 | 4.03 | 4.12 | 0.68 | 3.32 | 60 | 0.19 | 4.05 | 4.13 | 0.76 | 3.31 |
| 80 | 0.32 | 4.35 | 4.37 | 0.96 | 2.84 | 80 | 0.32 | 4.35 | 4.37 | 0.96 | 2.6 | 80 | 0.33 | 4.38 | 4.39 | 0.99 | 2.58 |
| 100 | 0.27 | 4.62 | 4.58 | 0.81 | 2.34 | 100 | 0.27 | 4.62 | 4.58 | 0.81 | 2.14 | 100 | 0.25 | 4.63 | 4.59 | 0.75 | 2.13 |
| 130 | 0.31 | 4.93 | 4.83 | 0.62 | 1.86 | 130 | 0.31 | 4.93 | 4.83 | 0.62 | 1.71 | 130 | 0.3 | 4.93 | 4.85 | 0.6 | 1.71 |

Table B3: Measurement furrow infiltration at 1st, 2nd and 3rd irrigation by volume balance method and computation of accumulated and average infiltration

**Treatment 3**

| After 1st irrigation | | | | | | After 2nd irrigation | | | | | | After 3rd irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) |
| 5 | 2.26 | 2.27 | 2.31 | 27.12 | 25.93 | 5 | 2.25 | 2.25 | 2.29 | 27 | 29.83 | 5 | 2.25 | 2.25 | 2.29 | 27 | 29.85 |
| 10 | 0.51 | 2.78 | 2.75 | 6.12 | 14.38 | 10 | 0.51 | 2.76 | 2.74 | 6.12 | 16.42 | 10 | 0.52 | 2.77 | 2.74 | 6.24 | 16.43 |
| 20 | 0.46 | 3.24 | 3.24 | 2.76 | 7.98 | 20 | 0.5 | 3.26 | 3.24 | 3 | 9.04 | 20 | 0.49 | 3.26 | 3.24 | 2.94 | 9.04 |
| 30 | 0.35 | 3.59 | 3.55 | 2.1 | 5.65 | 30 | 0.32 | 3.58 | 3.55 | 1.92 | 6.37 | 30 | 0.32 | 3.58 | 3.55 | 1.92 | 6.38 |
| 45 | 0.26 | 3.85 | 3.88 | 1.04 | 4 | 45 | 0.29 | 3.87 | 3.88 | 1.16 | 4.49 | 45 | 0.29 | 3.87 | 3.88 | 1.16 | 4.5 |
| 60 | 0.18 | 4.03 | 4.12 | 0.72 | 3.13 | 60 | 0.17 | 4.04 | 4.12 | 0.68 | 3.51 | 60 | 0.18 | 4.05 | 4.12 | 0.72 | 3.51 |
| 80 | 0.33 | 4.36 | 4.38 | 0.99 | 2.45 | 80 | 0.32 | 4.36 | 4.38 | 0.96 | 2.74 | 80 | 0.32 | 4.37 | 4.38 | 0.96 | 2.74 |
| 100 | 0.27 | 4.63 | 4.59 | 0.81 | 2.03 | 100 | 0.25 | 4.61 | 4.58 | 0.75 | 2.26 | 100 | 0.23 | 4.6 | 4.58 | 0.69 | 2.26 |
| 130 | 0.3 | 4.93 | 4.84 | 0.6 | 1.62 | 130 | 0.32 | 4.93 | 4.83 | 0.64 | 1.8 | 130 | 0.33 | 4.93 | 4.83 | 0.66 | 1.8 |

Table B4: Measurement furrow infiltration at 1st, 2nd and 3rd irrigation by volume balance method and computation of accumulated and average infiltration

**Treatment 4**

| After 1st irrigation | | | | | | After 2nd irrigation | | | | | | After 3rd irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. inflt. rate (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated avg. infilt. (cm/h) |
| 5 | 2.27 | 2.27 | 2.29 | 27.24 | 24.99 | 5 | 2.27 | 2.28 | 2.32 | 27.24 | 16.42 | 5 | 2.27 | 2.27 | 2.30 | 27.24 | 17.38 |
| 10 | 0.49 | 2.76 | 2.73 | 5.88 | 13.9 | 10 | 0.47 | 2.75 | 2.73 | 5.64 | 9.36 | 10 | 0.47 | 2.74 | 2.72 | 5.64 | 9.88 |
| 20 | 0.47 | 3.23 | 3.22 | 2.82 | 7.73 | 20 | 0.49 | 3.24 | 3.21 | 2.94 | 5.33 | 20 | 0.5 | 3.24 | 3.21 | 3 | 5.61 |
| 30 | 0.34 | 3.57 | 3.54 | 2.04 | 3.48 | 30 | 0.29 | 3.53 | 3.52 | 1.74 | 3.84 | 30 | 0.29 | 3.53 | 3.52 | 1.74 | 4.03 |
| 45 | 0.27 | 3.84 | 3.87 | 1.08 | 3.39 | 45 | 0.34 | 3.87 | 3.86 | 1.36 | 2.76 | 45 | 0.32 | 3.85 | 3.86 | 1.28 | 2.9 |
| 60 | 0.2 | 4.04 | 4.12 | 0.8 | 3.05 | 60 | 0.17 | 4.04 | 4.11 | 0.68 | 2.18 | 60 | 0.19 | 4.04 | 4.11 | 0.76 | 2.29 |
| 80 | 0.29 | 4.33 | 4.38 | 0.87 | 2.39 | 80 | 0.31 | 4.35 | 4.38 | 0.93 | 1.73 | 80 | 0.32 | 4.36 | 4.38 | 0.96 | 1.81 |
| 100 | 0.34 | 4.67 | 4.59 | 1.02 | 1.98 | 100 | 0.31 | 4.66 | 4.59 | 0.93 | 1.44 | 100 | 0.3 | 4.66 | 4.59 | 0.9 | 1.51 |
| 130 | 0.24 | 4.91 | 4.84 | 0.48 | 1.58 | 130 | 0.26 | 4.92 | 4.86 | 0.52 | 1.16 | 130 | 0.26 | 4.92 | 4.87 | 0.52 | 1.22 |

Table B5: Measurement furrow infiltration at 1st, 2nd and 3rd irrigation by volume balance method and computation of accumulated and average infiltration

**Treatment 5**

| After 1st irrigation | | | | | | After 2nd irrigation | | | | | | After 3rd irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) | Elapsed time (min) | Infiltration depth (cm) | Obs. accu. Infilt. (cm) | Simulated accu. Infilt. (cm) | Obs. avg. infilt. (cm/h) | Simulated. avg. infilt. (cm/h) |
| 5 | 2.27 | 2.28 | 2.30 | 27.24 | 26.13 | 5 | 2.27 | 2.28 | 2.31 | 27.24 | 26.97 | 5 | 2.27 | 2.28 | 2.31 | 27.24 | 26.87 |
| 10 | 0.48 | 2.76 | 2.74 | 5.76 | 14.5 | 10 | 0.49 | 2.77 | 2.75 | 5.88 | 14.93 | 10 | 0.49 | 2.77 | 2.75 | 5.88 | 14.88 |
| 20 | 0.47 | 3.23 | 3.23 | 2.82 | 8.04 | 20 | 0.51 | 3.28 | 3.24 | 3.06 | 8.26 | 20 | 0.5 | 3.27 | 3.24 | 3 | 8.24 |
| 30 | 0.36 | 3.59 | 3.54 | 2.16 | 5.69 | 30 | 0.3 | 3.58 | 3.55 | 1.8 | 5.85 | 30 | 0.31 | 3.58 | 3.55 | 1.86 | 5.83 |
| 45 | 0.26 | 3.85 | 3.87 | 1.04 | 4.03 | 45 | 0.27 | 3.85 | 3.88 | 1.08 | 4.13 | 45 | 0.28 | 3.86 | 3.88 | 1.12 | 4.13 |
| 60 | 0.2 | 4.05 | 4.12 | 0.8 | 3.16 | 60 | 0.2 | 4.05 | 4.13 | 0.8 | 3.23 | 60 | 0.19 | 4.05 | 4.13 | 0.76 | 3.23 |
| 80 | 0.28 | 4.33 | 4.38 | 0.84 | 2.47 | 80 | 0.29 | 4.34 | 4.39 | 0.87 | 2.53 | 80 | 0.3 | 4.35 | 4.39 | 0.9 | 2.53 |
| 100 | 0.35 | 4.68 | 4.59 | 1.05 | 2.04 | 100 | 0.33 | 4.67 | 4.59 | 0.99 | 2.09 | 100 | 0.33 | 4.68 | 4.60 | 0.99 | 2.09 |
| 130 | 0.23 | 4.91 | 4.84 | 0.46 | 1.63 | 130 | 0.26 | 4.93 | 4.84 | 0.52 | 1.67 | 130 | 0.25 | 4.93 | 4.85 | 0.5 | 1.67 |

## APPENDIX-C

### Sample calculation of infiltration test for fitting to modified Kostiakov equation

Using the field data presented in appendix-A the procedure in determining the values of a, α and b, and evaluating the goodness of fit, are described below.

Solution: From the plot of y against t (Fig. 4.1)

For $t_1 = 5$ minutes, $y_1 = 2.27$ cm, and

$t_2 = 130$ minutes, $y_2 = 4.9$ cm

Adopting the procedure suggested by Davis (1943), the rectifying value of t is found from the following relationships:

$$t_3 = \sqrt{t_1 \times t_2} \qquad \ldots (1)$$

$$t_3 = \sqrt{5 \times 130}$$

$t_3 = 25.5$ minutes

The corresponding value of $y_3$, as determined from Fig. 4.1 is 3.40 cm. The value of the constant b is obtained as follows:

$$b = \frac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2y_3}$$

$$b = \frac{2.27 \times 4.9 - (3.40)^2}{2.27 + 4.9 - 2 \times 3.40}$$

$b = -1.181$

The value -1.181 of b is subtracted from each value of y in appendix-A. The logarithms of (y+1.181) and t are taken. The variables are related by the expression

$$y + 1.181 = at^{\alpha}$$

The logarithmic from of which is

$$\log(y + 1.181) = \log a + \alpha \log t \qquad \ldots (2)$$

The logarithmic from of the expression will then be log y = log a + α log t. The other steps in the computation of the values of a and α, and the verification of the goodness of fit are same in both types of equations.

Substituting the data on average infiltration y and elapsed time t presented in Table 4.1 into equation 2 yields the following eleven equations:

0.5379 = log a + 0.699 α

0.5956 = log a + 1.000 α

0.6445 = log a + 1.301 α

0.6740 = log a + 1.477 α

0.7050 = log a + 1.653 α

0.7185 = log a + 1.778 α

0.7412 = log a + 1.903 α

0.7679 = log a + 2.000 α

0.7839 = log a + 2.114 α

Adding the first five and last four equations

3.1572 = 5 log a + 6.1303 α

3.0117 = 4 log a + 7.7952 α

Multiplying (ii) by 5 and (i) by 4

12.6288 = 20 log a + 24.5212 α

$15.0585 = 20 \log a + 38.976\, \alpha$

Solving simultaneously

$\alpha = 0.1681$

$\log a = 0.4253$

$a = 2.6628$

Figure 4.1 is the plot of y against t on log-log paper. To determine the goodness of fit the values of y are calculated by substituting the values of a, α and b in the equation $y = at^{\alpha} + b$ for each observed value of t. The values of t are substituted in the equation as follows in the logarithmic from:

$\log (y - b) = \log a + \alpha \log t$

we have, at

t = 5 minutes

$\log (y_1 + 1.181) = 0.4253 + 0.1681 \times 0.699$

$y_1 = 2.3086$ cm

t = 10 minutes

$\log (y_2 + 1.181) = 0.4253 + 0.1681 \times 1.00$

$y_2 = 2.7400$ cm

t = 20 minutes

$\log (y_3 + 1.181) = 0.4253 + 0.1681 \times 1.301$

$y_3 = 3.2245$ cm

t = 30 minutes

$$\log (y_4 + 1.181) = 0.4253 + 0.1681 \times 1.477$$

$$y_4 = 3.5353 \text{ cm}$$

t = 45 minutes

$$\log (y_5 + 1.181) = 0.4253 + 0.1681 \times 1.653$$

$$y_5 = 3.8679 \text{ cm}$$

t = 60 minutes

$$\log (y_6 + 1.181) = 0.4253 + 0.1618 \times 1.778$$

$$y_6 = 4.1181 \text{ cm}$$

t = 80 minutes

$$\log (y_7 + 1.181) = 0.4253 + 0.1618 \times 1.903$$

$$y_7 = 4.3807 \text{ cm}$$

t = 100 minutes

$$\log (y_8 + 1.181) = 0.4253 + 0.1618 \times 2.00$$

$$y_8 = 4.5933 \text{ cm}$$

t = 130 minutes

$$\log (y_9 + 1.181) = 0.4253 + 0.1618 \times 2.114$$

$$y_9 = 4.8535 \text{ cm}$$

## APPENDIX-D

Table D: Moisture content under 1st, 2nd and 3rd irrigation in different treatments

| Depth (cm) | After 1st irrigation | | | | | After 2nd irrigation | | | | | After 3rd irrigation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| 0-15 | 19.3 | 17.7 | 17.4 | 16.8 | 16.6 | 19.6 | 17.9 | 17.8 | 16.87 | 16.62 | 19.95 | 18.64 | 17.98 | 16.97 | 16.8 |
| 15-30 | 19.5 | 18.2 | 17.8 | 17.4 | 16.9 | 19.8 | 18.6 | 18.2 | 17.8 | 16.95 | 20.62 | 19.38 | 18.76 | 18.07 | 17.39 |
| 30-45 | 19.8 | 19.4 | 18.32 | 17.9 | 17.3 | 20.77 | 19.86 | 18.97 | 18.59 | 17.53 | 21.28 | 20.59 | 19.79 | 18.98 | 18.19 |

## APPENDIX-E

Table G: Gross cost of cultivation of *brinjal* (converted to Rs./ ha) under different treatments

| Particular | Treatment | | | | |
|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| Field preparation | 19535.53 | 19535.53 | 19535.53 | 19535.53 | 19535.53 |
| Fertilizer cost | 6095.238 | 6095.238 | 6095.238 | 6095.238 | 6095.238 |
| Manure cost | 6827.839 | 6827.839 | 6827.839 | 6827.839 | 6827.839 |
| Nursery cost | 9142.857 | 9142.857 | 9142.857 | 9142.857 | 9142.857 |
| Insecticide | 2147.985 | 2147.985 | 2147.985 | 2147.985 | 2147.985 |
| Plastic mulch | 16000.00 | | | | |
| Saw dust mulch | | | 10256.41 | | |
| Labour cost | 18315.02 | 17289.38 | 14945.05 | 13919.41 | 11721.61 |
| Total = | 78064.47 | 61038.83 | 68950.92 | 57668.86 | 55471.06 |

Table G: Gross profit from cultivation of *brinjal (*converted to Rs./ha) and benefit-cost ratio under different treatments

| Particular | Treatments | | | | |
|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| Total yield of Brinjal (q)/ha | 448.70 | 350.70 | 342.60 | 338.70 | 332.30 |
| Marketable yield (q)/ha | 430.70 | 308.60 | 333.40 | 286.90 | 272.40 |
| Selling price @ Rs./q | 700.00 | 700.00 | 700.00 | 700.00 | 700.00 |
| Gross profit from marketable yield, Rs. | 301490.00 | 216020.00 | 233380.00 | 200830.00 | 190680.00 |
| Gross cost of cultivation, Rs. | 78064.47 | 61038.83 | 68950.92 | 57668.86 | 55471.06 |
| Benefit cost ratio | 3.86 | 3.53 | 3.38 | 3.48 | 3.43 |

# RESUME

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