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# EVALUATING THE ROLE OF BENTONITE EMBEDMENT IN CONTROLLING INFILTRATION AND IMPROVE ROOT ZONE WATER DISTRIBUTION IN COARSE SOIL

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An extensive irrigation system is being developed in Greater Thal Canal area to meet food demand of growing population. In Greater Thal Canal area soils are predominately coarse which results in higher deep percolation losses than those occurring in other cultivated land. Surface irrigation methods are normally used. Infiltration may be described by the Kostiakov Equation. Soil amendments such as bentonite could be used to reduce the water infiltration rate. The objectives of the study were to control the infiltration in the coarse soil by using bentonite admixture and improve water distribution uniformity. For this SIRMOD model was used which showed that water traveled only 19 m along the field with no amendment because all the water percolated deep before reaching at the field end. When 1% bentonite was mixed with soil, water did not reach at field end but traversed 32 m for 2.54 cm mix depth, 38 m for 7.62 cm mix depth, 39 m for 5.04 cm mix depth and 37 m for 30 cm mix depth. When 2% bentonite was mixed with soil, water reached the tail end of field with distribution uniformity of 80% for 2.54 cm mix depth, 84.5% for 5.04 cm mix depth, 90.9% for 7.62 cm mix depth and 84.9% for 30 cm mix depth. The best combination observed in lab. and field tests was 2% bentonite in any depth (2.54 cm - 30 cm). Hence the amendment of sandy soils with bentonite is one of the good options to lower infiltration rate and increase water use efficiency.
**Keywords:** Kostiakov Eq., bentonite, SIRMOD model, surface irrigation, infiltration, water use efficiency

## INTRODUCTION

Food demand is increasing in Pakistan due to population growth thus marginally available land is increasingly being brought under irrigation as Thal, Cholistan, Thar deserts and vast barren areas of Balochistan in Pakistan, where soils are predominately coarse. For this study Greater Thal Canal (GTC) was selected where an extensive irrigation system is being developed and surface irrigation method (Basin) is likely to be used.

In Pakistan inefficient surface irrigation is used in majority of the irrigated agriculture lands which has some major water use efficiency issues. Our fields are not designed according to the soil infiltration rate and the available flow, the application and distribution efficiencies are quite low so large volume of precious irrigation water is deep percolated. These losses represent considerable financial loss in term of reduced productivity. It is imperative to save water to achieve higher productivity per unit of water consumed. Therefore it requires to explore new ways and means to reduce the losses. Surface irrigation is usually favored because of its lower energy, labor and cost requirements. However, the lower efficiency of surface irrigation restricts its use. Modern techniques like bentonite amendment can be used for high efficient surface irrigation methods. In surface irrigation methods the flow medium of water is soil so the soil type directly affects the water distribution efficiency. The infiltration characteristic of the soil is the most essential factor affecting the performance of surface irrigation (Lee *et al.*, 2011; Udom *et al.*, 2011; Khatri and Smith, 2005). Among many models developed for monitoring the infiltration process those of Kostiakov (1932) has been studied in detail because of their simplicity and the ease of estimating their fitting parameters. Kostiakov Infiltration Equation is:

$$F = a\,\tau^{b} + f_o\,\tau$$

F = Cumulative infiltration rate ($m^3$/m of length)
$\tau$ = Intake opportunity time (minutes)
a = Empirical constant ($m^3/min^b/m$)
b = Empirical exponent (dimensionless) and
$f_o$ = Final infiltration or Basic intake rate ($m^3$/min/m)

The predicted values of cumulative infiltration with calibrated Kostiakov model when plotted against observed data gave a good fit (Osman *et al*., 2003). The performance of a level basin designed based upon the completion of advance phase is more robust than the performance of a level basin irrigation system (Reddy, 2011). This reduces the difference of intake opportunity time between the head and tail ends of a field and thus leads to more uniform water application in root zone. High infiltration rate increases the time to complete irrigation advance phase and thus the uniformity of water to the root zone decreases.

The soil can be stabilized with various materials, including lime and bentonite. Bentonite is particularly well-suited clay for use in the formation of fluid barriers. When wetted, bentonite swells, or hydrates, by absorbing films of water that are thicker than those which form on other clays. The water absorbed by bentonite is retained even when subjected to high pressures. Bentonite is capable of swelling as much as ten to fifteen times its dry volume, and can absorb water to almost five times its own dry weight, while retaining its impermeability (Clem, 1992). Bentonite slurry mixed with original base soil is successfully used for sealing dam foundations.

The objectives of the study were to control the infiltration in the coarse soil by the use of bentonite admixture and improve water distribution uniformity.

## MATERIAL AND METHODS

***Site description*:** The soils of the Greater Thal Canal area are predominantly coarse and moderately coarse textured and are generally free of salinity and alkalinity. The earlier studies show that the area comprises 76.54% coarse, 18.10% moderately coarse, 4.84% medium and 0.45% fine texture soil. The remaining 0.07% is covered by marshland. GTC is designed to irrigate the field via gravity flow.

Infiltration tests and irrigation water distribution evaluation were initially conducted in the lab. for a soil material resembling that of GTC area. The tests and irrigation evaluation was subsequently tested on GTC soils. For lab. experiments samples were collected from the River Ravi near Saghiyan Bridge, Lahore. It was found from the sieve analysis that the percentage of soil components of lab. sample was 95% sand, 3% silt and traces of clay. The percentage of soil components of field (GTC) sample was found 96% sand, 4% silt and traces of clay.

***Lab infiltration tests*:** For Infiltration tests, concrete (without collar) drain pipes of one meter length were installed with suitable interspacing. All pipes were installed at the same height. Soil samples were placed in the vertical and leveled infiltrometer pipes. Sample length was 60 cm in each pipe. Detail of depth and percentage of bentonite mixing is shown in Table 1.

***Field infiltration test*:** Field experiments were conducted at 35+000RD left side of Greater Thal Canal. Double ring infiltrometer was used to measure infiltration rate. List of experiments performed in the field are shown in Table 2. Calculated infiltration parameters determined by using matching curve method were then used for further calculations in SIRMOD.

***SIRMOD model inputs*:** SIRMOD model can accurately simulate continuous and surge flow irrigation under short field conditions when the appropriate infiltration parameters are used (Saleh, 2005). SIRMOD model was used to determine irrigation application performance without and with bentonite admixture. Following was the constant data used in SIRMOD model:

Field length = 60 m   as Acre size is 60×67 m
Field width = Half Acre (33.5 m)
Discharge = 1.5 cfs = 1.25 lps/m of width
Roughness coefficient = 0.04
Targeted infiltration depth = 0.05 m
Time of cut off = 50 min.

## RESULTS

***Infiltration parameters for lab tests*:** Kostiakov curve fitting parameters were calculated using curve fitting method for different depth and percentage of bentonite mixing of soil

**Table 1. Depth and percentage of bentonite mixing in soil**

| Pipe No. | Depth of Mixing | Weight of soil (g) | Percentage of bentonite mixed | Weight of bentonite (g) |
|---|---|---|---|---|
| 1 | -Nil- | | -Nil- | |
| 2 | 2.54 cm (1") | 2175 | 1% | 21.75 |
| 3 | 2.54 cm (1") | 2175 | 2% | 43.5 |
| 4 | 5.08 cm (2") | 4350 | 1% | 43.5 |
| 5 | 5.08 cm (2") | 4350 | 2% | 87 |
| 6 | 7.62 cm (3") | 6525 | 1% | 65.25 |
| 7 | 7.62 cm (3") | 6525 | 2% | 130.5 |
| 8 | 30 cm | 26100 | 1% | 261 |
| 9 | 30 cm | 26100 | 2% | 522 |

**Table 2. List of experiments performed in fields**

| S. No. | Depth of mixing | Percentage of bentonite mixed (By weight) |
|---|---|---|
| Test 1 | -Nil- | -Nil- |
| Test 2 | 5.08 cm (2") | 2 % |

sample. Curve fitting parameters of Kostiakov equation before mixing bentonite were a=0.016, b=0.655 and $f_o$=0.0004 as shown in Figure 1a. The curve fitting parameters were a=0.011, b=0.59 and $f_o$ =0.0004 when 1% by weight dry bentonite was mixed in 2.54 cm depth of sample (Fig. 1b). When 1% bentonite mixed in 5.08 cm depth of sample, the fitting parameters of Kostiakov equation were a=0.0097, b=0.56 and $f_o$ =0.0004 (Fig. 1c).

When 2% bentonite was mixed in 2.54cm depth of sample, the fitting parameters of Kostiakov equation were a=0.0064, b=0.4 and $f_o$=0.00038 as shown in Figure 1d. Mixing of 2% bentonite in 5.08 cm depth of sample, resulted the fitting parameters of Kostiakov equation as a=0.0052, b=0.37 and $f_o$=0.00038 (Fig. 1e). When 1% bentonite was mixed in 7.62 cm depth of sample, the fitting parameters of Kostiakov equation were a=0.0099, b=0.565 and $f_o$=0.0004 (Fig. 1f).

When 2% bentonite was mixed in 7.62 cm depth of sample, the fitting parameters of Kostiakov equation were a=0.0065, b=0.38 and $f_o$=0.00039 (Fig. 1g). 1% bentonite mixing in 30 cm depth of sample gave fitting parameters of Kostiakov equation as a=0.0095, b=0.538 and $f_o$=0.0004 (Fig. 1h). When 2% bentonite was mixed in 30 cm depth of sample, the fitting parameters of Kostiakov equation were a=0.0056, b=0.35 and $f_o$= 0.00038 (Fig. 1i).

***Infiltration parameters for field tests*:** Kostiakov curve fitting parameters for field infiltration tests for different depth and percentage of bentonite mixing of soil sample are shown in Figure 2. Kostiakov curve fitting parameters for field (GTC) infiltration tests of sample (sandy soil) before mixing bentonite were a=0.012, b=0.7 and $f_o$=0.0004 as shown in Figure 2(a). The curve fitting parameters were a=0.0066, b=0.383 and $f_o$=0.00038 when 2% by weight bentonite was mixed in 5.08 cm depth of sample (Fig. 2b).

***SIRMOD results for lab tests*:** SIRMOD results for lab sample are shown in Figure 3. It was found that before mixing of bentonite, water traveled only 19 m along the field because all the water deep percolated before reaching the tail and water deep percolation depth was 0.24 m (Fig. 3a).

A little improvement was seen when 1% bentonite was mixed in 2.54 cm depth, for this case water traversed 32 m (half length) and water deep percolation depth was decreased to 0.15 m (Fig. 3b). When 1% bentonite was mixed in 5.08 cm depth, SIRMOD results showed that water traveled only 39 m and water deep percolation depth was reduced to 0.13 m as shown in Figure 3c). Water traveled only 38 m when 1% bentonite mixed in 7.62 cm depth of lab sample and water deep percolation depth was reduced to 0.125 m (Fig. 3d). Water traveled only 37 m when 1% bentonite mixed in 30 cm depth and water deep percolation depth was reduced to 0.125 m (Fig. 3e).

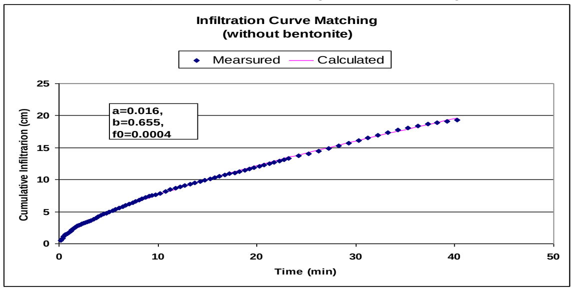
Mixing of 2% bentonite in 2.54 cm depth in lab sample resulted in Application Efficiency of 91%, Storage Efficiency of 97% and Distribution Efficiency of 80% (Fig. 3f). When 2% bentonite was mixed in 5.08 cm depth, satisfactory results were obtained and water deep percolation depth was reduced to 0.05 m, water reached at the end of the field with Application Efficiency of 100%, Storage Efficiency of 95.6% and Distribution Efficiency of 84.5% (Fig. 3g). When 2% bentonite was mixed in 7.62 cm depth in lab sample, satisfactory results were obtained and water deep percolation depth was reduced to 0.05 m. Water reached at the end of the field with Application Efficiency of 90.9%, Storage Efficiency of 96.6% and Distribution Efficiency of 80.7% (Fig. 3h). When 2% bentonite mixed in 30 cm depth in lab sample, again satisfactory results were obtained and water deep percolation depth was reduced to 0.06 m. Water reached at the end of the field with Application Efficiency of 100%, Storage Efficiency of 95.4% and Distribution Efficiency of 84.9% (Fig. 3i).

***SIRMOD results for field tests*:** It was found from lab experiments that 2% bentonite is enough for controlling infiltration rate and enhances water distribution efficiency. These results then were tested in the field. SIRMOD results for field (GTC) tests are shown in Figure 4. It was found that before mixing of bentonite, all the water deep percolated before reaching at the tail and water traveled only 10 m along the field and water deep percolation depth was 0.43 m (Fig. 4a). When 2% bentonite mixed in 5.08 cm depth, satisfactory results were obtained as in lab test and water deep percolation depth was reduced to 0.06 m. Water reached at the end of the field with Application Efficiency of 90%, Storage Efficiency of 96.6% and Distribution Efficiency of 80.5% (Fig. 4b). Similar results were found in the field as well. Little variation in SIRMOD results for Lab and field test was due to the difference in soil structure.

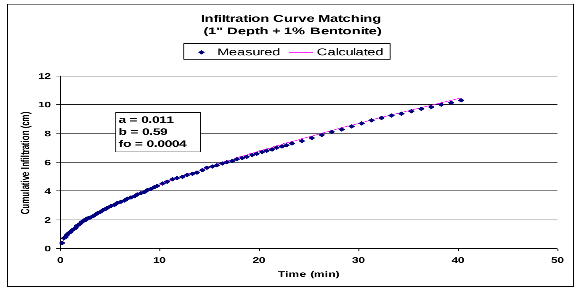
## DISCUSSION

It is evident from the results that bentonite reduced the Kostiakov infiltration parameters. The drop-off in all Kostiakov equation parameter values after mixing of bentonite was due to the reduction of infiltration rate which was due to the swelling effect of bentonite. Bentonite works significantly in reducing infiltration and improves the irrigation efficiency satisfactory. SIRMOD results revealed that water cannot reach at the tail end of the field because all water was deep percolated within 19 m, as the infiltration rate of the sample soil of lab and GTC area is very high. When 1% bentonite by weight was mixed in the sample in different depths the SIRMOD results showed that water travelled only 32 m – 39 m. This movement of water is not satisfactory. Water could be reached at the end of field if apply more discharge of water for long duration which causes the more deep percolation losses. This could not be possible because of shortage of water.

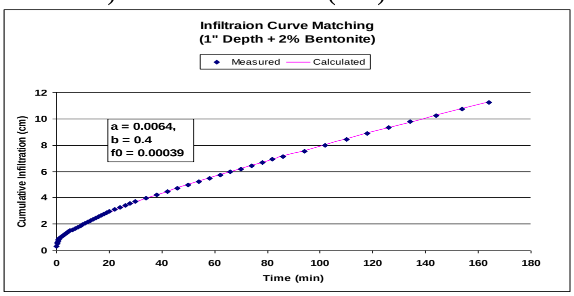
When 2% by weight bentonite clay was mixed in sample with different depths the SIRMOD results were satisfactory and water reached at the tail end with minimum advance time. Bentonite (2%) worked very effectively which increased application efficiency up to 89-100%, storage



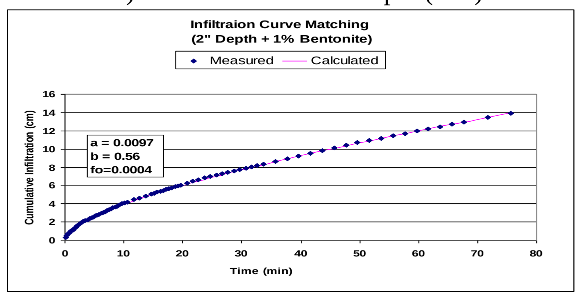

a) Without Bentonite (Lab)



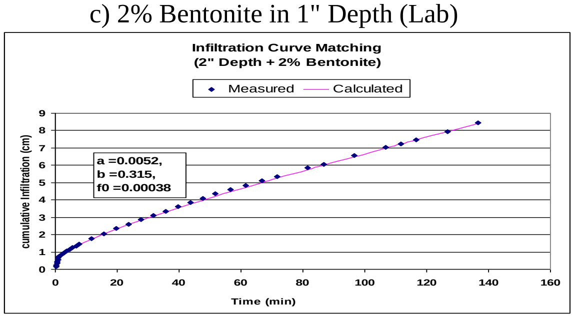

b) 1% Bentonite in 1" Depth (Lab)



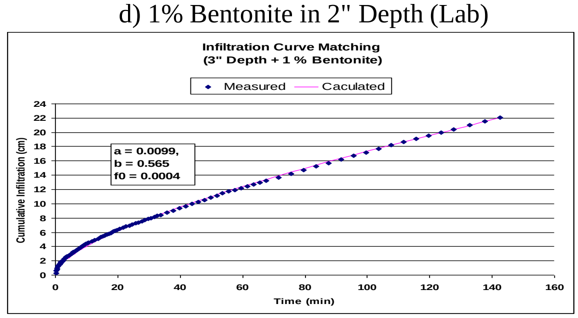

c) 2% Bentonite in 1" Depth (Lab)



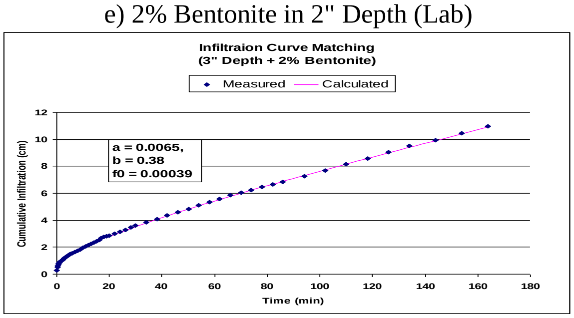

d) 1% Bentonite in 2" Depth (Lab)



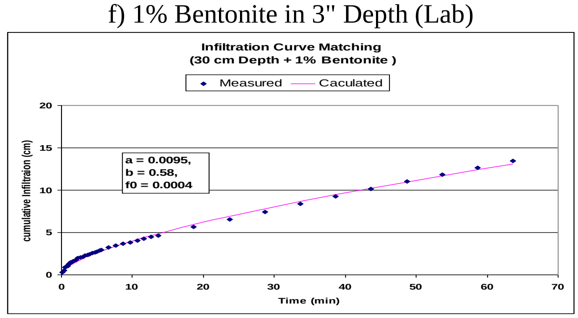

e) 2% Bentonite in 2" Depth (Lab)



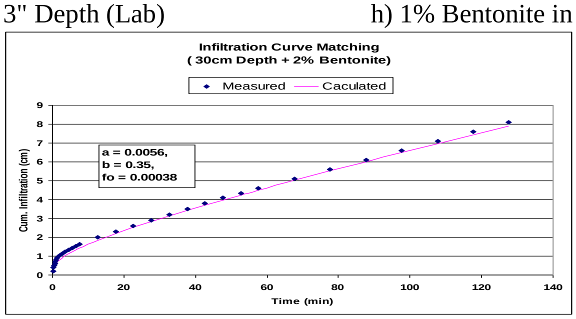

f) 1% Bentonite in 3" Depth (Lab)




g) 2% Bentonite in 3" Depth (Lab)

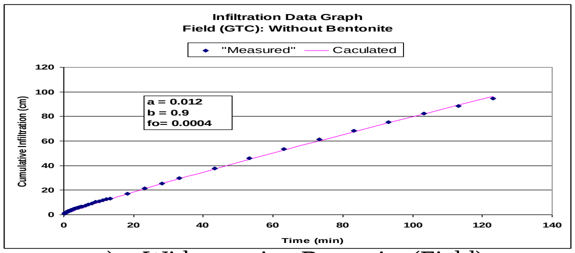



h) 1% Bentonite in 30 cm Depth (Lab)

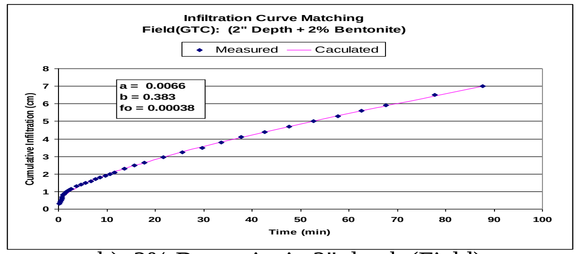



i) 2% Bentonite in 30 cm Depth (Lab)

**Figure 1. Determination of Kostiakov equation parameters for Lab tests**

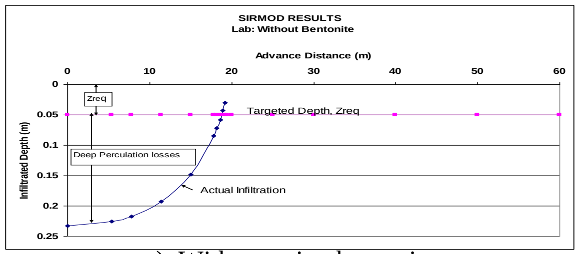



a) Without using Bentonite (Field)

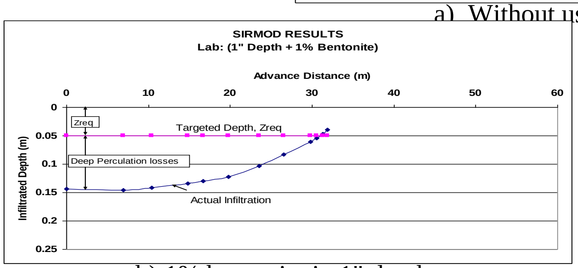



b) 2% Bentonite in 2" depth (Field)

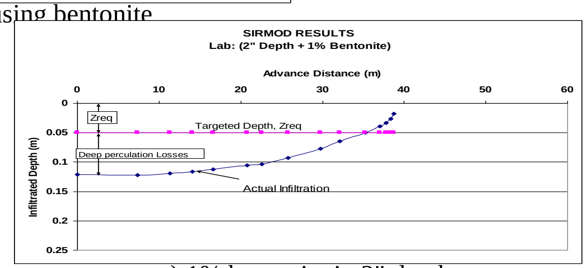
**Figure 2. Determination of Kostiakov equation parameters for field tests**



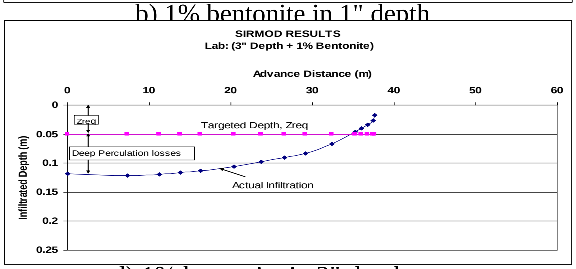

a) Without using bentonite



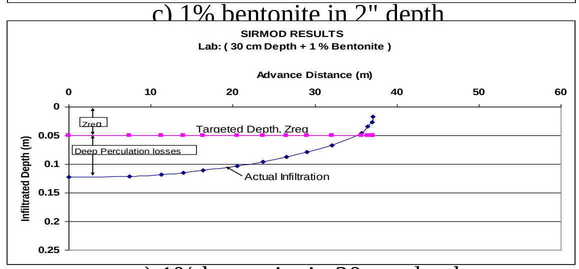

b) 1% bentonite in 1" depth



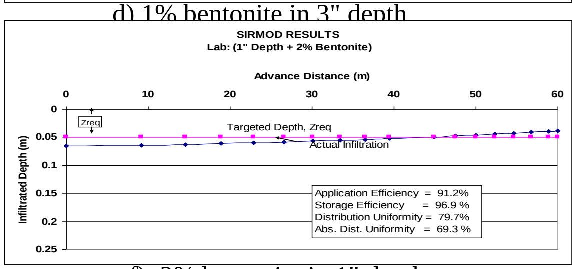

c) 1% bentonite in 2" depth



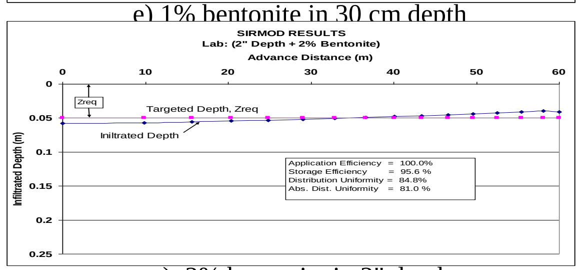

d) 1% bentonite in 3" depth



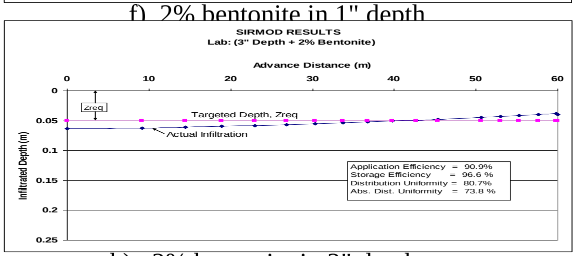

e) 1% bentonite in 30 cm depth



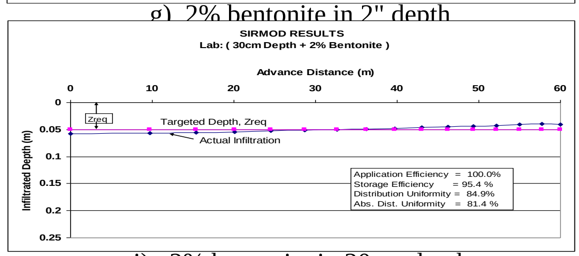

f) 2% bentonite in 1" depth




g) 2% bentonite in 2" depth

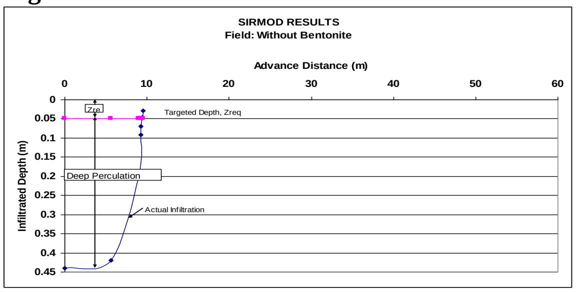



h) 2% bentonite in 3" depth

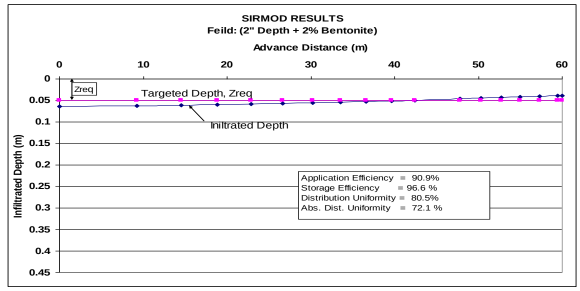



i) 2% bentonite in 30cm depth

**Figure 3. SIRMOD results for Lab tests**




a) Without Bentonite (Field)




b) 2% bentonite in 2" Depth (Field)

**Figure 4. SIRMOD results for field tests**

efficiency 90-97% and distribution uniformity 80-100%. Ismail *et al*. (2007) found similar results and concluded that the 45% - 64% water use efficiency and water saving increased by clay applications. Bentonite (2%) is recommended in any depth up to 30 cm (12") depth, soil will give good results. More than 2% bentonite can seal or near to seal the downward movement of water and water will remain on the soil surface which will not be available to roots. As 5% by weight bentonite is enough for ceiling of canal beds to prevent seepage losses (Tariq, 2009). Bentonite should be mixed after harvesting of previous crop and field preparation and before planting of next crop.

For long term bentonite amendment may be made 2% by weight in 30 cm depth. To mix the bentonite uniformly, bentonite must be totally dried. Spread bentonite in field manually or with seed spreaders on the top of the surface then by using rotavator mix the soil and bentonite as per selected depth to make uniform admixture. Rotavator can be used for shallow depth of mixing up to 2.54 cm – 15.24 cm. About 2-3 passages of rotavator are required for complete mixing. For deep depth mixing up to 30 cm depth tine cultivator would be used for uniform mixing. About 3-4 passages of tine cultivator are required for complete soil and bentonite mixing.

***Conclusions*:** Addition of bentonite decreased the infiltration rate of coarser soil and improved the irrigation water distribution. The Kostiakov infiltration equation parameters a, b and $f_o$ decreased when percentage of bentonite increased. The percentage of bentonite mix is more significant than the depth of mix in reducing infiltration rate. For 1% bentonite mixing the irrigation water did not reach at the end of the field and advance distance was limited to 30 to 40 m only for various mix depth. For 2% bentonite mixing the water reached the tail end of the field and distribution uniformity varied from 80 to 85% for various mix depth. 2% bentonite by weight mixed in any depth (2.54 to 30 cm) of soil produced satisfactory results for lowering infiltration rate. The cost of amendments of 2% bentonite mixing is Pak. Rs. 21600, 43200, 64800 and 255100 per acre for mixing depth of 2.54, 5.08, 7.62 and 30 cm, respectively.

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