

IMPACT OF THE CHANGE OF SOIL TEXTURE ON THE INFILTRATION BEHAVIOR OF SOILS IN THE EARTHEN IRRIGATION CANALS OF LGDIMA AND HANABOU

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ABSTRACT

This work was devoted to the study of the infiltration at the laboratory on samples of soil taken from the irrigation channels Lgdima and Hanabou located in the irrigated area of Jorf which belongs to the province of Errachidia (Morocco). The experimental device is composed of glass test-tubes containing the samples to be tested. The test-tubes were subjected to a constant water head during all the tests, which consisted of the recording of the infiltration time versus the advance of the humidification front in the test-tubes. All the samples underwent the same energy of dry compaction. In all the experiments, the infiltration measurements concerned the samples from origin soils not compacted, then compacted and finally mixed with fractions of clay according to percentages from 5 to 25%. The two parameters analyzed in the experiments are the water infiltration time necessary to cross entirely the soil column and the infiltration rate. The objective of this paper is to test the impact of change in the soil characteristics on the infiltration behavior, while keeping constant the other parameters such as the initial water content and the compaction degree.

The results showed in a first stage of the experimentation, that the comparison between infiltration times in the same sample not compacted then compacted, allows us to get a ratio between the two times higher than 2. This shows the effect of the compaction on the deceleration of the humidification front and thus on that of the infiltration. In one second stage, the infiltration time was measured in a case where the two samples of origin soil were compacted then mixed with clay. The results of these tests indicated that the variation of the infiltration time is an increasing function of the clay fraction brought and it is that this variation is better represented by a second order parabolic law with determination coefficients (R^2) of 0,972 and 0,983, respectively, for Lgdima and Hanabou samples. The study of the variation of the infiltration rate $I(t)$ versus the time t , made it possible to get in the case of the two samples, curves whose the best fit is a power function with a coefficient of determination R^2 ranging between 0,909 and 0,995. The equation of the infiltration rate was found to be as: $I(t) = \alpha t^{-\beta}$, α and β are coefficients which vary from a sample to another and from one test to another.

Keywords: Infiltration, Humidification front, Clay fraction, Infiltration rate, Compaction.

1. INTRODUCTION

Proper management of irrigation water can be considered as one of the key factors in ensuring good agricultural production. Particularly in the small and medium irrigated areas in Morocco, where a large part of the irrigated lands only partially lined irrigation networks. The loss of water in earthen channels is related to a number of factors, among which we can first mention the infiltration of water into the soil. Improving the efficiency of transport or distribution of water in earthen channels, means looking for ways to reduce water losses in these channels, and therefore limit the infiltration of water into the soil of the channel bed. To achieve this goal, it is essential to study the

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behavior of infiltration in the soil while making the necessary surveys on the factors that affect the movement of water in the soil. The rate of infiltration is a parameter that could oscillate between low and high values within the same locality because of the disparity that could possibly exist between the characteristics of the soils at this locality.

The objective of this study is to conduct a number of infiltration tests on samples taken from the soils composing two earthen channels in the small and medium irrigated area of Jorf, Province of Errachidia. Through these tests, we hope to study the impact that the change in the texture of the original soil could have on the behavior of the infiltration.

Several research studies have been carried out to study the infiltration in soils but the consistency of this work differs according to the desired objectives. Abdelwahab (2000) found that the design, operation, management and use of water at the plot level are strongly related to the properties of soil infiltration. This is explained by the fact that the behavior of the infiltration in a soil conditions the other variables such as the flow, the length of the water course, the depth of percolation and other. Jianfeng and Kenneth (2008) provided a summary of the different models of infiltration. They showed that the infiltration rate is influenced by the initial water content, the nature of the soil surface, the hydraulic conductivity, the texture, the porosity, the degree of swelling of the colloids, the organic matter, the duration of the irrigation and the irrigation water viscosity. The work of Adeniji (et al) (2013) concluded that the infiltration rate is closely related to the fine fraction of the soil. He provided a model for estimating the infiltration rate of a soil at a given time if the fine fraction of this soil is known. Razavipour and Farrokh (2014) found that there is a relation between the clay fraction present in the soil and its permeability according to a parabolic standard law of order 2. They have also demonstrated that the permeability of the soils tested decreases with increasing the fraction of clay to finally arrive at a constant value when this fraction exceeds 40%. Ngom (2015) has shown that the addition of the original soil clay considerably reduces infiltration rates and that this decrease depends on the amount of clay added.

2. MATERIAL AND METHODS

The samples were taken from the irrigation channels tested in the Jorf irrigated area located in the Tafilalet region. The channels sampled are : Lgdima and El Alouia Hanabou. The particle size analysis of these samples, carried out in the laboratory of the Department of Natural Resources and Environment of the IAV, made it possible to know the texture of the samples analyzed. Other clay samples were taken from the Oulja quarry in Salé. The experimental test includes the following steps : (i) removal of all impurities in the sample; (ii) grinding of coarse elements; (iii) sifting the samples using a 2mm sieve; (iv) drying in an oven for 24 hours; (v) placement of the sample in the test tube per 10 cm column. Depending on the case, the sample of the original soil is mixed with the clay in well-defined proportions; (vi) compaction of each slice of soil by 10 cm maintaining a drop height and a constant number of strokes for each test until a compacted soil column is obtained over a height of 40 cm; (vii) continuous water supply of the sample while guaranteeing a constant water head of 5 cm throughout the test and (viii) measurement of the advancement of the wetting front using a graduated scale as a function of time.

The equipment used consists of a device for demonstrating infiltration (Figure 1) comprising a 2000 ml graduated test tube, a tray which collects the infiltrated water and a base that supports the test tubes. The base is equipped with circular membranes pierced in an appropriate mesh ensuring the retention of soil particles without blocking the downward flow of water.



Figure 1. Infiltration demonstration apparatus

3. RESULTS AND DISCUSSION

3.1 Study of Laboratory Infiltration in the Original Soil Samples

In a first step, the behavior of the infiltration in the two samples was studied: Lgdima and El Alouia Hanabou. For the two samples, two infiltration tests were conducted. The first test is performed without compaction and the second with compaction. The recorded measurements of the advance of the humidification front in the samples, as a function of time, are illustrated by the curves of figure 2.

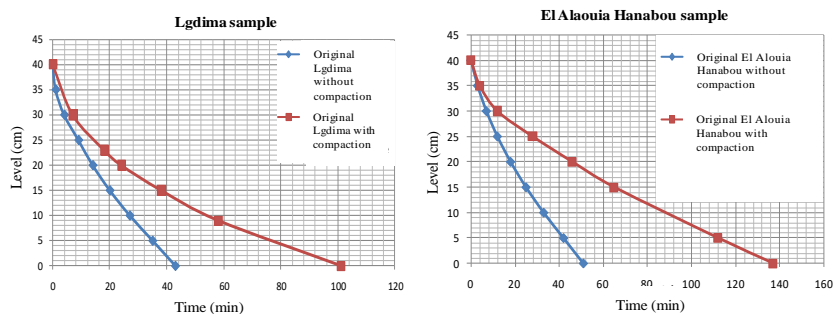


Figure 2 . Analysis of the infiltration in the original soil samples of Lgdima and El Alouia Hanabou channels

These graphs show that for the case of the Lgdima sample, the advance time of the infiltration front in the uncompacted sample is $t_{nc} = 43$ minutes. By compacting the sample, this time is $t_c = 101$ minutes. For the El Alouia Hanabou sample, $t_{nc} = 51$ min and $t_c = 137$ min. It is also noted that t varies slightly from one sample to another. In both cases, the times t_{nc} and t_c relating to the Hanabou sample are greater than those of the Lgdima sample. This finding highlights the effect of soil texture on the behavior of water infiltration into soil. Moreover, a comparison between the crossing times, in the absence and in the presence of compaction, shows that the ratio between the two times (t_c / t_{nc}) is greater than 2. This clearly shows that compaction also has an effect on slowing the humidification front.

3.2 Study of Laboratory Infiltration in the Original Soil Samples Mixed with Clay

In a second step, the same experiment was repeated except that the samples initially tested were mixed with the clay in different proportions (5%, 10%, 15%, 20%, 25%). The curves of variation of the progress of the humidification front versus time are presented in figure 3 and 4. From these two graphical representations, it appears that for each of the two samples, the crossing time varies according to the proportion of clay supplied to the sample. It increases when the fraction of clay mixed with the compacted

soil is increased. As shown in Table 1, by varying this fraction from 0 to 25% in steps of 5%, it can be seen that for Lgdima sample, this time varies between 109 mn and 2380 mn and for Hanabou sample, it varies from 137 mn to 1462 mn.

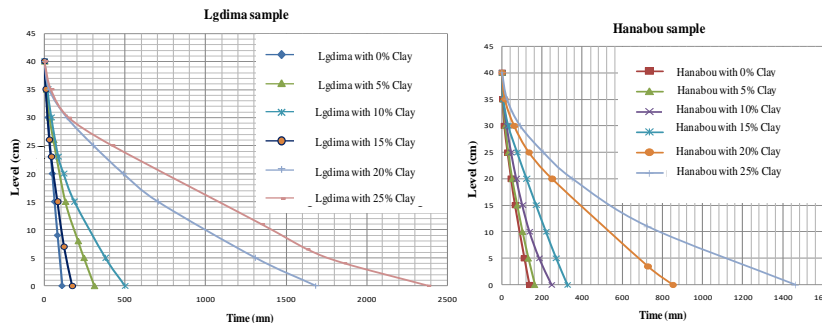


Figure 3. Analysis of infiltration in samples of Lgdima and El Alouia Hanabou channels mixed with different clay fractions

Table 1. Crossing time of the infiltration front for Lgdima and Hanabou samples according to the fraction of clay brought

% Clay	Time (mn)	
	Lgdima sample	Hanabou sample
0	109	137
5	170	162
10	310	247
15	499	326
20	1685	850
25	2380	1462

The data shown in Table 1 were used to graphically represent the variation of the soil column transit time as a function of the proportion of clay added. The curves obtained are shown in Figure 4 below :

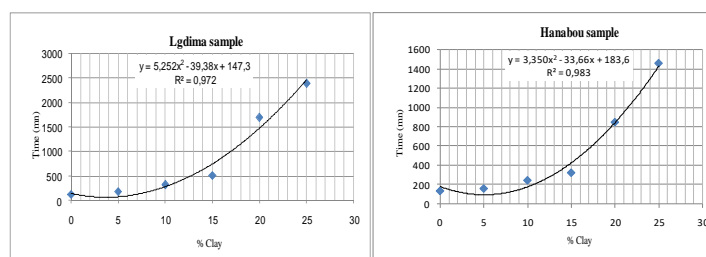


Figure 4. Variation Curves of the crossing time of the soil columns by the humidification front in the Lgdima and Hanabou samples

The two curves in figure 4 demonstrate the existence of a strong correlation between the crossing time and the clay fraction brought to the compacted soils of Lgdima and Hanabou samples. As shown, the variation of the humidification time is an increasing function of the fraction of clay provided, and it is better translated by a second order parabolic law with determination coefficients (R^2) of 0.972 and 0.983, respectively, for the Lgdima and Hanabou samples. The equations are indicated on the graphics. The difference between the coefficients a, b and c of the two equations could be explained by the difference in the textures of the two samples. In fact, the particle size analysis of

the original samples made it possible to classify them in the sandy loam (Lgdima) and silt (Hanabou) classes. By using the regressions equations derived from the curves in Figure 4, it would be possible to predict the behavior of the infiltration in the columns tested by simulating the humidification time necessary to fully cover the soil column. The proportions of simulated clay are those that have not been tested in the laboratory. The results are shown in Table 2 below :

Table 2. Simulation of the infiltration time versus the fraction of clay added

	% Clay	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Time (day)	Lgdima	2,6	3,6	4,8	6,3	7,9	9,6	11,6	13,7	16,1	18,6	21,3	24,1	27,2	30,4	33,8
	Hanabou	1,5	2,2	2,9	3,8	4,8	5,9	7,1	8,4	9,9	11,5	13,1	14,9	16,9	18,9	21,1

These results show that the crossing time could vary from 2.6 to 33.8 days when the clay fraction was varied from 30 to 100% in the case of the Lgdima sample. This time varied from 1.5 to 21.1 days in the case of the Hanabou sample. In the light of these results, it can be concluded that it is possible to delay the advance of the humidification front in a soil column, and therefore reduce infiltration, without infinitely increasing the clay fraction to be mixed with the soil. For both samples, a time exceeding 1.5 days is already observed when a clay fraction of 30% is reached.

3.3 Laboratory Analysis of the Infiltration Rate According to the Progress of the Humidification Front in the Lgdima and Hanabou Samples

It is also noted that the infiltration rate, calculated from the ratio of the difference of advancing dimensions of the humidification front to that of the corresponding times, varies according to the humidification depth on the one hand; and secondly depending on the fraction of clay provided . Indeed, and as shown in Tables 3 and 4, the rate of infiltration decreases as a function of the depth of advance of the moistening front, for a fixed fraction of clay. Moreover, this rate tends to decrease with the progressive increase of the fraction of clay mixed with the original compacted sample.

Table 3. Infiltration rate as a function of the progress of the humidification front for different clay fractions made to Lgdima sample

0 % Clay		5 % Clay		10 % Clay		15 % Clay		20 % Clay		25 % Clay	
Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)
40		40		40		40		40		40	
35	286	35	375	35	273	35	158	35	100	35	75
30	261	30	250	30	143	30	125	30	27	30	27
23	233	26	240	26	100	23	98	25	18	25	11
20	225	23	164	15	89	20	55	20	16	11	9
15	214	15	123	8	53	15	45	15	14	6	9
9	200	7	120	5	50	5	31	5	10	4	7
0	186	0	84	0	46	0	25	0	8	0	5

Table 4. Infiltration rate as a function of the progress of the humidification front for different fractions of clay brought to the Hanabou sample

0 % Clay		5 % Clay		10 % Clay		15 % Clay		20 % Clay		25 % Clay	
Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)	Level (cm)	Infiltration rate (mm/h)
40		40		40		40		40		40	
35	750	35	750	35	500	35	429	35	214	35	120
30	375	30	250	30	176	30	125	30	65	30	46
25	188	25	200	25	136	25	68	25	41	25	26
20	167	20	158	20	115	20	64	20	26	20	21
15	158	15	120	15	100	15	63	15	20	15	16
10	130	10	115	10	83	10	61	10	21	10	13
5	125	5	103	5	63	5	59	5	21	5	9
0	120	0	94	0	48	0	54	0	18	0	8

3.4 Laboratory Analysis of Infiltration Rate as a Function of Humidification Time in Lgdima and Hanabou Samples

In each test, the infiltration rate was determined as a function of the advancing time of the humidification front in the soil columns relative to the two samples. The variable of each test is the proportion of clay mixed with the original compacted sample, which varies from 0 to 25% by adopting a step of 5%. The results of the calculations are presented in Tables 5 and 6.

Table 5. Infiltration rate as a function of humidification time for different clay fractions made to the Lgdima sample

0 % Clay		5 % Clay		10 % Clay		15 % Clay		20 % Clay		25 % Clay	
Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)
0		0		0		0		0		0	
10.5	286	8	375	11	273	19	158	30	100	40	75
22	261	20	250	32	143	43	125	140	27	150	27
40	233	30	240	56	100	86	98	305	18	420	11
48	225	41	164	130	89	119	55	490	16	1345	9
62	214	80	123	209	53	186	45	705	14	1630	9
80	200	120	120	245	50	378	31	1310	10	1860	7
109	186	170	84	310	46	499	25	1685	8	2380	5

Table 6. Infiltration rate as a function of humidification time for different clay fractions in the Hanabou sample

0 % Clay		5 % Clay		10 % Clay		15 % Clay		20 % Clay		25 % Clay	
Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)	Time (mn)	Infiltration rate (mm/h)
0		0		0		0		0		0	
4	750	4	750	6	500	7	429	14	214	25	120
12	375	16	250	23	176	31	125	60	65	90	46
28	188	31	200	45	136	75	68	133	41	205	26
46	167	50	158	71	115	122	64	248	26	350	21
65	158	75	120	101	100	170	63	400	20	540	16
88	130	101	115	137	83	219	61	540	21	780	13
112	125	130	103	185	63	270	59	680	21	1120	9
137	120	162	94	247	48	326	54	850	18	1462	8

Table 5 and 6 data were used to plot graphs of infiltration rate in figures 5 and 6. The best-suited regression type is a power function with a coefficient of determination R^2 between 0.906 and 0.995. These results show that there is a very good correlation between infiltration rate and time. The trend curves obey a power law given by the expression :

$$I(t) = \alpha t^{-\beta} \quad (1)$$

α and β are coefficients that vary from one sample to another and from one test to another. The values of α and β are mentioned in Table 7.

Table 7. Values of the α and β coefficients determined for different clay fractions in the Lgdima and Hanabou samples

Sample		Lgdima			Hanabou		
Test N ^o	Clay fraction (%)	α	β	R ²	α	β	R ²
1	0	451,6	0,18	0,982	1353	0,52	0,961
2	5	1050	0,47	0,967	1358	0,54	0,974
3	10	906,8	0,52	0,973	1303	0,58	0,978
4	15	1063	0,59	0,958	885,6	0,51	0,906
5	20	622,7	0,59	0,972	835,7	0,59	0,958
6	25	592,9	0,6	0,944	964,8	0,66	0,995

The relationship of infiltration rate as a function of time as it was released from the 12 graphs validates the well-known relation in the bibliography, namely that the rate of infiltration decreases with time and ends up asymptotically to a constant value which represents the saturation hydraulic conductivity. The same form of equation was recommended by Kostiakov in 1932 and given by the expression :

$$I = Kt^{-n} \quad (2)$$

K and n being respectively a coefficient and an exponent such that : $0 < n < 1$. A comparison between equations (1) and (2) validates the interval of β since, in all tests, β is between 0.18 and 0.66. It is clear that α and β condition the behavior of the infiltration in the two samples. Table 7 clearly shows that α and β vary according to the initial texture and to the fraction of clay added. So, we can conclude that the rate of infiltration in a given soil, could be voluntarily modified and even anticipated, just by acting on its initial texture.

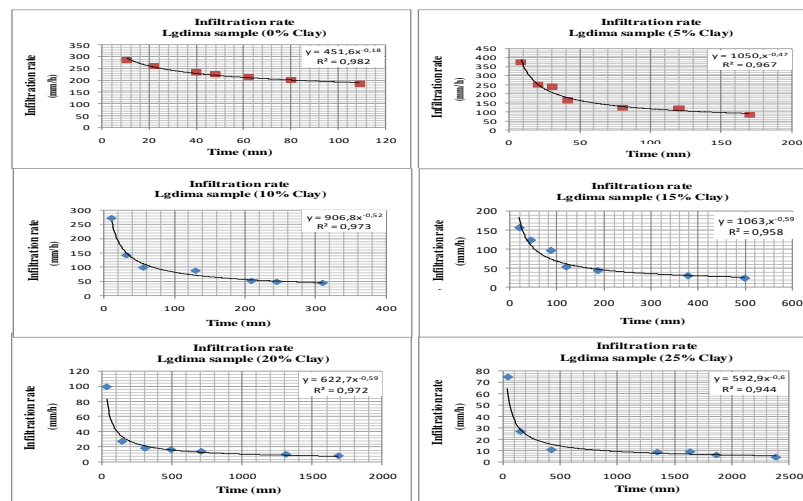


Figure 5. Graphical representations of the infiltration rate for the Lgdima sample

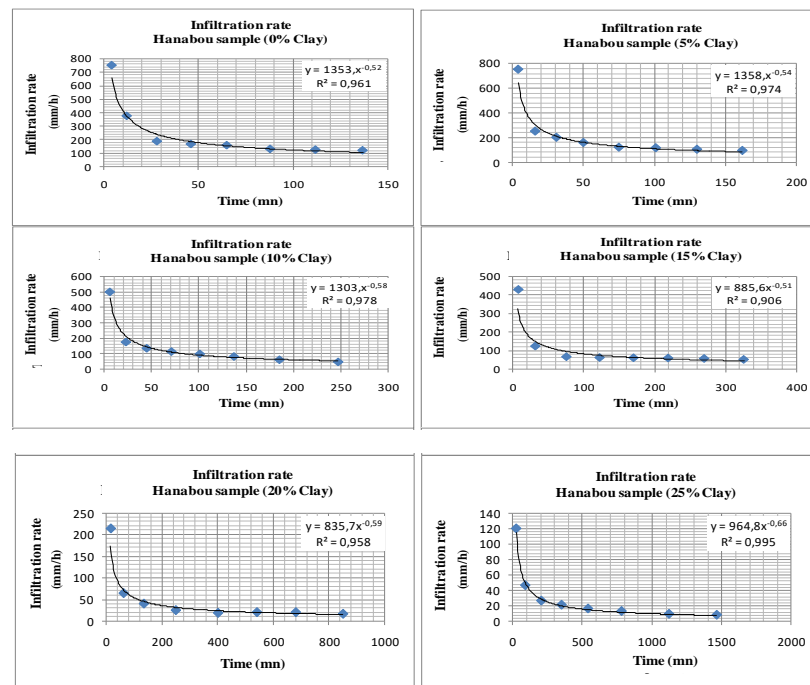


Figure 6. Graphical representation of the infiltration rate for the Hanabou sample

Another interpretation of the curves presented in Figures 5 and 6, is based on the calculation of a clogging index I_c from the initial and final infiltration rates in each test. This index is defined by the following relation :

$$I_c (\%) = \frac{I_i - I_f}{I_i} \times 100 \quad (3)$$

I_i and I_f , respectively, are the infiltration rates at the beginning and at the end of the test. The calculation results of I_c are given in Table 8 below:

Table 8. Values of clogging indexes determined for different clay fractions in the Lgdima and Hanabou samples

Clay fraction added (%)	Clogging index (%)	
	Lgdima sample	Hanabou sample
0	34,8	84
5	77,6	87,5
10	83,1	90,3
20	84,3	91,8
25	93,8	93,7

Table 8 shows that in general I_c is between 77.6% and 93.8%. Thus, I_c increases with the clay fraction to reach respective values of 93.7% and 93.8% when the clay fraction reaches 25%. For this value, the infiltration rate is reduced by about 94%. This underlines the crucial role played by clay in reducing the infiltration rate and seepage losses in the channels from which the samples were taken. In figure 7, I_c is plotted versus the clay fraction. The variations of I_c obey a polynomial law. The coefficients of determination are respectively 0.857 and 0.974 for the Lgdima and Hanabou samples. In order to see the trend of the variation of I_c , a simulation was made for the clay

fractions of 30%, 35% and 40% not tested. The results are recorded in Table 9 and the curves in Figure 8.

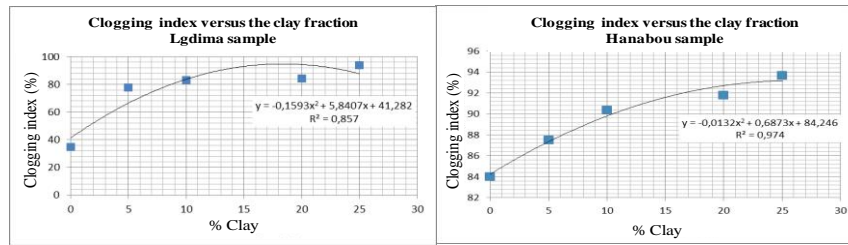


Figure 7. Change in the clogging index as a function of the clay fraction added to the Lgdima and Hanabou samples

Table 9. Values of clogging indices supplemented by simulation for untested clay fractions (30% -35% - 40%)

Added clay fraction (%)	Clogging index (%)	
	Lgdima sample	Hanabou sample
0	34,8	84
5	77,6	87,5
10	83,1	90,3
20	84,3	91,8
25	93,8	93,7
30	73,1	93
35	50,6	92,1
40	20	90,6

The simulation of the variation of I_c as indicated by the figure 8, shows a decrease of I_c when the fraction of clay exceeds 25%. In other words, the difference ($I_i - I_r$) ceases to increase once the clay fraction has reached 30%. Thus, there is an optimal value of the clay fraction to be added without necessarily being the largest (100%), for which it is hoped to see a maximum reduction in the rate infiltration and subsequently to a significant reduction in losses in the earthen channels which were sampled.

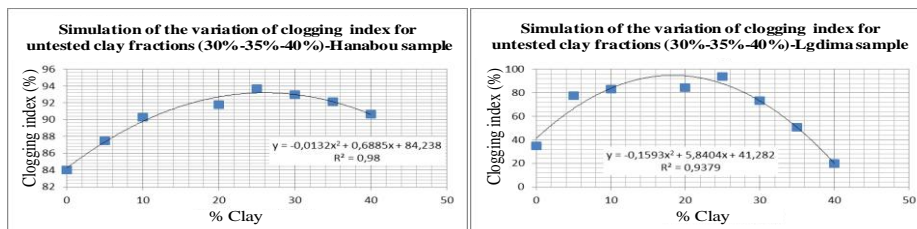


Figure 8. Simulation of the variation of the clogging index for untested clay fractions in the Lgdima and Hanabou samples

4. CONCLUSION

The results of the present work indicate that, in a first step of the experiment, the comparison between the humidification times in the same sample of the soil which has not been compacted and then compacted, has shown that the two times are in a ratio

greater than 2. This shows the effect of compaction on the slowing of the humidification front in the soil columns tested and thus on the infiltration.

In a second stage, in which the soil composition of the two samples was modified by the contribution of different clay fractions ranging from 5% to 25%, the results show that the infiltration is strongly related to soil composition. This is evidenced by the regression equations of the curves obtained. Indeed, the coefficients of determination vary from 0.944 and 0.982 in the case of the Lgdima sample, and from 0.906 to 0.995 for the Hanabou sample. These results attest to the existence of a very good correlation between infiltration rate and time, translated by : $I(t) = \alpha t^{-\beta}$ in which α and β vary from one sample to another and from one test to another. In all the tests, β varies between 0.18 and 0.66, which allows us to conclude that the equation of infiltration rate released from the tests is similar to that recommended by Kostiakov in which $\beta \in]0,1[$. Therefore, it can be concluded that the rate of infiltration in a given soil, could be voluntarily modified and even anticipated, just by acting on its initial texture. Although the textures of the two samples tested are close, it is found that the infiltration rate curves are different. This can be explained by the fact that the percentage distribution of solid grains according to their dimensions is different in the two samples. In other words, the behavior of infiltration, which is related to the importance of water loss in a given soil, may be different in another soil whose texture is very similar to that of the first.

By defining a parameter called clogging index (I_c), it would be possible to determine an optimum fraction of clay that must be brought to the samples in order to achieve a pronounced reduction of the infiltration in these samples and consequently to a reduction in infiltration losses in the earthen channels from which these samples were taken. Through the results of this work, it was possible to highlight the impact of the change of texture of the soil of origin on the behavior of the infiltration in this soil. The mixture of the original soil with different clay fractions has been translated by a change in the rate of infiltration. It is therefore assumed that this modification is likely to condition the water flows that enter the soil and as a result, one could hope to be able to control water losses in an earthen canal in order to improve its efficiency.

5. REFERENCES

- Abdel Wahab, D. M.(2000). Evaluation, Prediction And Optimization Of Long Furrow Irrigation Under Kenana Conditions. P.H.D. Dissertation. Water Management And Irrigation Institute, University Of Gezira,Wad Medani, Sudan.
- Adeniji F. A., Umara B. G., Dibal J. M. And Amali A. A. (2013). Variation Of Infiltration Rates With Soil Texture. A Laboratory Study. International Journal Of Engineering And Innovative Technology (IJEIT) Volume 3, Issue 2, August 2013. Department Agricultural And Environmental Resources Engineering, Faculty Of Engineering, University Of Maiduguri, Maiduguri. Borno State Nigeria.
- Jianfeng X., And Kenneth, G. (2008). Effect Of Rainfall Intensity On Infiltration Into Partly Saturated Slopes. Publication Information.Geotechnical And Geological Engineering, 26 (2): 199-209.
- Ngom A. (2015). Essais D'infiltration En Vue De L'amélioration De L'efficience Des Canaux D'irrigation En Terre Dans La Petite Et Moyenne Hydraulique (Cas De Jorf-Arfoud). Projet De Fin d'Etudes Pour L'obtention Du Diplôme d'Ingénieur d'Etat En Génie Rural.
- Razavipour T. And A.R. Farrokh (2014). Measurement Of Vertical Water Percolation Through Different Soil Textures Of Paddy Field During Rice Growth Season. International Journal Of Advanced Biological And Biomedical Research. Volume 2, Issue 5.