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Performance Evaluation of Sub–Surface Drainage System in Melka Sedi

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No. 23

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Contents

INTRODUCTION

The area selected for the pilot drainage scheme was at the eastern corner of the Melka Sedi Banana Farm, and in the southern part of the Amibara irrigation project (Fig.1). The scheme was constructed in 1983, on 35 ha of land and operation commenced in the same year. Monitoring work was also started just after the completion of the scheme and preliminary results were presented in a report (7).

The site was characterized by high temperature and low humidity, resulting in a considerably high evapotranspiration rate, while the average annual rainfall is only about 550 mm. This was summarized from class I weather station at Melka Werer Research Center (Appendix 4).

The soil of the pilot scheme area was surveyed in 1969 and 1971 by an Italian consultant as part of the feasibility study for the larger area of Amibara Irrigation Project. The survey result characterized the area as layered soils of variable texture, and described generally as non-saline and non-sodic. Further surveys were also conducted in 1975 and 1981 (5) including the pilot drainage scheme.

Subsequent surveys with the earlier feasibility studies showed that the pilot drainage scheme soils are deep, dark-brown and generally loamy, with a high silt and very fine sand content. They frequently show textural stratification in the profile, presumably resulting from deposition cycles on the Awash flood plain by fluvial activity from streams draining the escarpment to the south west. Generally a relative impermeable layer of silty-clay was observed at three meter depth from the soil surface. Hydraulic conductivity values of the soil varied from 0.1 to 5 m day^{-1} (7).

The initial salinity of the area varied from place to place. Ground water table fluctuated around 1.5 m from the surface of the soil, and salt concentration ranged from 5 to 35 ds m^{-1}. Part of the scheme was left fallow for a long period (Field 4c/6 and 4c/10) while the remaining was under banana plantation, with poor stand (Field 4c/7), before the installation of the drains.

Because of the existing high soil salinity, imperfect drainage condition and high ground water table, the area was regarded unfavorable for irrigated agriculture. With this regard, the pilot drainage scheme was installed in 1983 to meet the following principal objectives:

- Verify the parameters used in theoretical design, including the drainage criterion and hydropedological factors,

- Determine the most appropriate combination of drainage pipes and envelope materials by studying the entrance resistance and water table drawdown characteristics.

- Examine the practicability of reclaiming the saline and saline-sodic soils by leaching only.

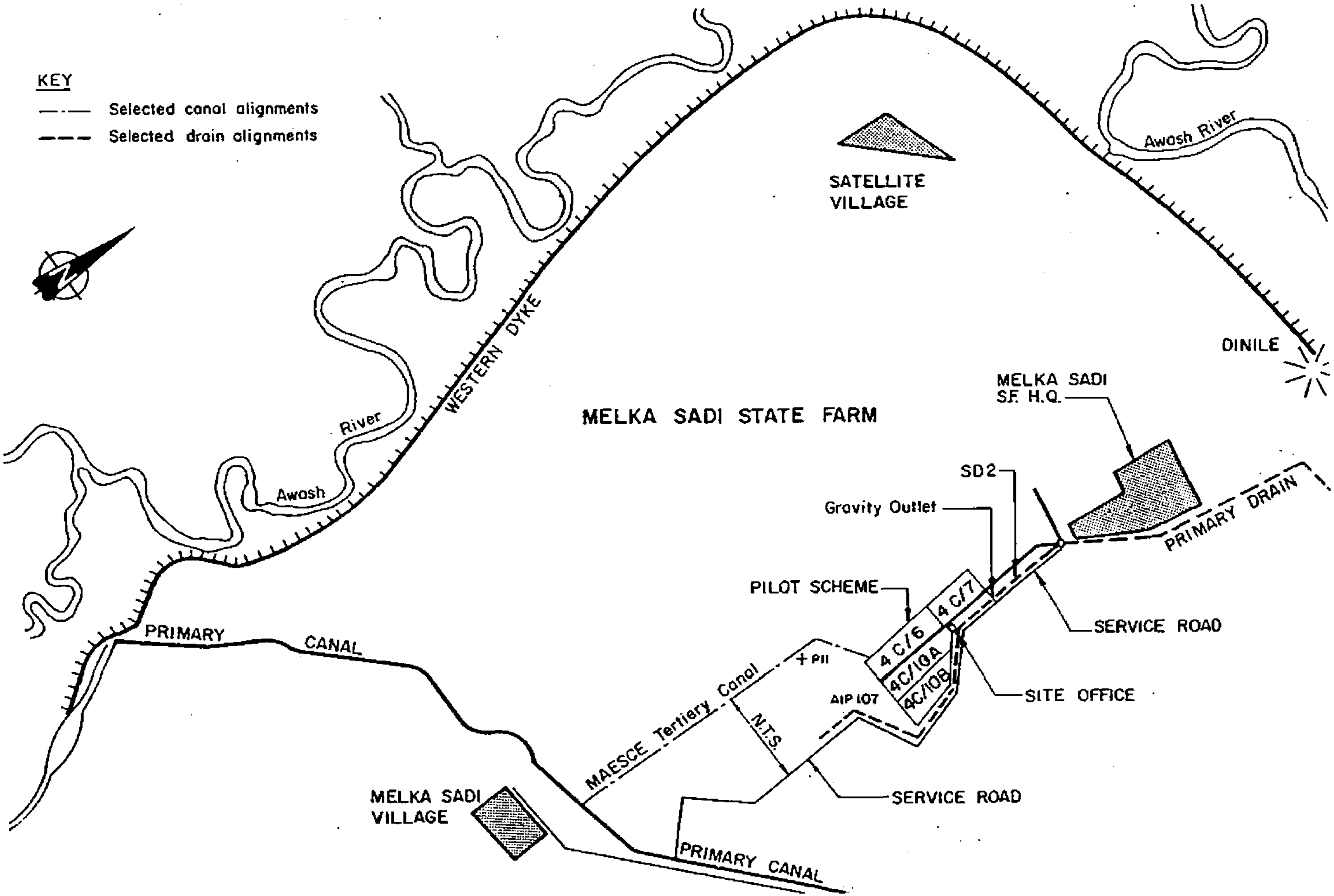

Figure 1. Location of the pilot drainage scheme

MATERIALS AND METHODS

The pilot drainage scheme is at Melka Sedi state farm on a medium textured stratified soils of alluvial origin. After installation of the drainage system, fields 4c/6 and 4c/7 were cropped cotton, while 4c/10a was cropped banana.

DRAIN LINE PERFORMANCE

Water application to the pilot drainage scheme was made every 21-days irrigation schedule. The amount (150 mm/irrigation) was measured using a parshall flume. Daily observations of the field drain discharge was measured using 20 litter capacity plastic bucket and stop watch. Beside this, hydraulic head was measured using piezometers three times a day to monitor the ground water fluctuation.

Soil Hydrological Constant

The data from field tests (discharge and hydraulic head) were processed to calculate the hydraulic conductivity (k) using the Hooghoudt and Boussinesq equations representing steady and non steady flow conditions respectively. The hydraulic heads of the mid drain piezometers were compared with the drain discharge of the respective testing drains to evaluate the drainage system (Tables 1 and 2).

Table 1. Combination of pipes and drainage materials tested

Drain line no.	Drain length (m)	Test line no.	Combinations	Pipe diameter (mm)	Slot size (m)	Spacing (mm)
D_1–D_6	225	D_3	Corrugated PVC + Gravel filter	60	1	75
[illegible]	225	[illegible]	Ditto	60	1	40
D_{16}–[illegible]	181	D_{18}	Ditto	60	2	40
D_{20}–[illegible]	181	D_{21}	Corrugated PVC + red ash filter	60	1	40
[illegible]	181	D_{24}	Corrugated PVC + factory made filter	60	1	40

Table 2. Piezometers used for testing the drainage system.

Test line	LHS			RHS		
drain	I	II	III	I	II	III
3 8 18 21	5 13 81 85	35 44 98 107	58 66 120 124	4 12 78 82	25 36 90 99	57 65 117 121

I, II, and III indicate row numbers at quarter, half and three quarters of drain length respectively.

LHS = left-hand side of the test drain RHS = right-hand side of the test drain

Steady state condition

Steady state conditions were considered to occur when the water table does not change position over a sufficiently long period, and the drain outflow remains the same. This steady state flow condition was studied based on the Hooghoudt formula (4).

$$q = \frac{8kdh}{s^2} + \frac{4kh2}{s^2} \qquad [1]$$

Where q = discharge rate per unit surface area (m day^{-1})
h = hydraulic head or water table elevation above drain level midway between the drains
k = hydraulic conductivity (m day^{-1})
s = drain spacing (m)
d = thickness of the so called equivalent layer (m)

$$d = \frac{Do}{\frac{8Do}{s} \ln \frac{Do}{U} + 1} \qquad [2]$$

Where Do = depth to relatively impermeable layer below drain level
U = wetted perimeter of the drain, (U = pie x r)
r is the radius of the pipe and pie = 3.14

From these equations 1 can be expressed as

$$q = Ah + Bh^2 \quad => \quad \frac{q}{h} = A + Bh$$

Where $A = \frac{8kd}{s^2}$ *and* $B = \frac{4k}{s^2}$

If flow below the drain is large, the q h^{-1} versus h relationship when plotted graphically, will be a horizontal straight line

$$\frac{q}{h} = \frac{8kd}{s^2} = A$$

Conversely, when the flow above the drain is large then the q h^{-1} versus h relationship is a straight line of gradient tan a

$$\tan a = \frac{4k}{s^2} = B$$

Therefore, q h^{-1} was regressed on to h by linear regression leading to the equation

$$\frac{q}{h} = A + Bh \qquad [3]$$

The above equations were used to evaluate the hydropedological constants and to verify the initial assumptions concerning the soil properties on which the design of the drainage system was based.
The Hooghoudt k value from A term will be calculated from the transmissivity (kd) and using the equivalent thickness (d) (table 3).

Unsteady state condition

The unsteady state flow condition can occur when there is water table fluctuation because of intermittent recharge by irrigation application or heavy storms. Under this flow condition hydraulic conductivity (k) was calculated by using Boussinesq equation with the relatively impermeable layer at drain level (4).

$$\frac{q}{h} = \frac{3.46\ k.h}{s^2} \qquad [4]$$

When q h^{-1} is plotted against h, a straight line with gradient (tan a) will be developed.
Then,

$$\tan a = \frac{3.46\,k}{s^2} \qquad (5)$$

Where

$$k = \frac{S^2 \tan a}{3.46}$$

Table 3. Equivalent thickness (d) of aquifer below drain depth from Hooghoudt [illegible]

Test line	Distance (Do) from drain depth to impervious base (m)* left-hand I	II	III	right-hand I	II	III	Equivalent thickness (d) using equation [illegible] left-hand I	II	III	right-hand I	[illegible]
3	1.0	1.0	1.0	3.0	3.0	3.0	0.9	0.9	0.9	2.4	[illegible]
6	1.3	1.3	1.3	1.3	1.3	1.3	1.1	1.1	1.1	1.1	[illegible]
18	0.5	0.5	1.0	0.5	0.5	1.0	0.5	0.5	0.9	0.5	0.5

* Source: William, H (1986)

Drainage Material Tests

Determination of entrance resistance

In the pilot drainage scheme, gravel, red–ash and factory made filters were tested as envelope materials. The performance of the filter material was assessed by measuring entrance head losses and drain discharge during flow events. A series of piezometers were installed across each test drains to measure the head fluctuation of the ground water . Daily measurements of piezometric head of each piezometer were made by using deep meter. Head loss (he_1) due to filter materials was measured as the difference between the readings of the piezometer located outside the drain envelope (0.3 m from the drain) and at that of the piezometer head in the drain itself. Head loss (he_2) was also measured between the piezometer on the drain and the piezometer at 1m from the drain which represents the head loss caused by the resistance of the disturbed zone of the installation trench (fig 2 and table 4).

Table 4. Piezometer numbers under investigation for entrance resistance

Test drain no.	left–hand (m) from drain center line 1.0	0.3	Center line 0	right–hand (m) from drain center line 0.3	1.0
3	32	31	30	29	28
21	105	104	103	102	101
24	114	113	112	111	110

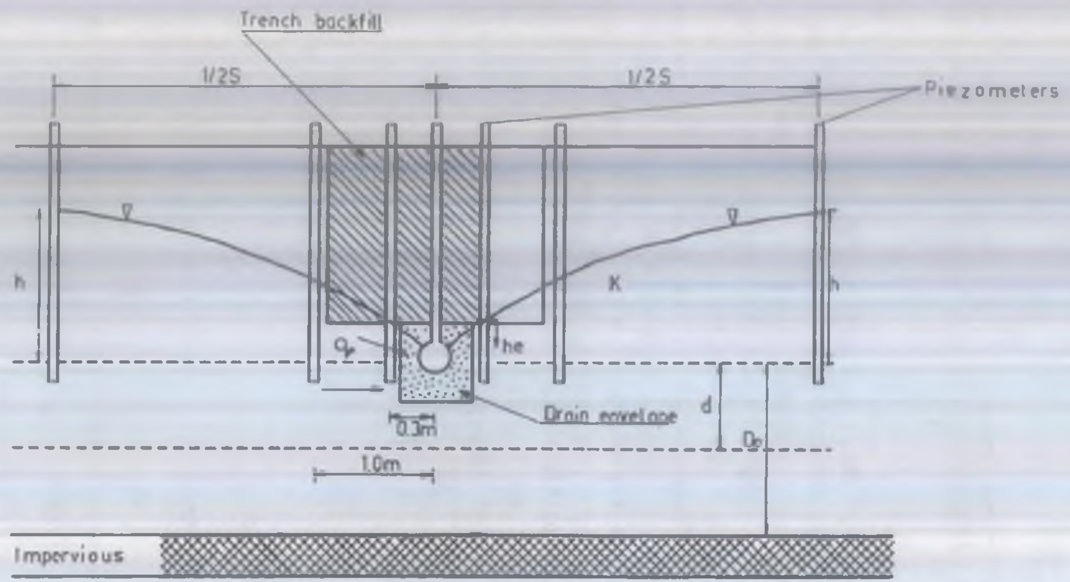

Figure 2. Symbols and piezometer line locations used in flow and entrance resistance equation at Melka Sedi pilot drainage scheme

The general equation that could be used for testing the performance of drainage materials using the entrance component is described as follows (2).

$$re = \frac{he}{qu} = \frac{he}{q.s} \qquad [6]$$

Where
re = entrance resistance in days m^{-1}
he =entrance head loss in meters
s = drain spacing (m)
qu =flow rate in m^2/day per meter length of drain
q = drain outflow rate per unit area, i.e.,

$$q = \frac{qu}{s} \; (m\ day^{-1})$$

From the above equation (6) the head loss can be derived as

$$he = reqs \qquad [7]$$

The value of head loss (he) can be plotted against the corresponding values of qs (discharge per unit length of the drain) and the line passing through the points was correlated by linear regression. Based on this, the scope of the line is the entrance resistance (re) of the drain pipe and envelope materials and/or the disturbed trench. The regression equation which could be obtained will be expressed as:

$$he = a + re(qs) \qquad [8]$$

Where a = residual value (m)

Therefore, the values of "re" and "a" were calculated by linear regression of he_1 and he_2 onto qs. The values of re_1 and a_1 are the entrance resistance and residual head resulting from the pipe and envelope. Where as, re_2 and a_2 are the entrance resistance and residual head resulting from the resistance due to trench disturbance.

For several combinations of drainage and filter materials calculations were made over four years (1987-1990). For this period, 64 events (tail recession periods) were analyzed including 650 daily discharge observations.

The performance of drain lines and materials for the entrance resistance was evaluated using FAO grading system (2) (table 5).

Table 5. Grading level of entrance resistance for drain line performance

Entrance resistance re (days m^{-1})	Entrance head loss (he) (m)	Drain line performance
< 0.75	< 0.15	Good
0.75 - 1.50	0.15 - 0.30	Moderate
1.50 - 2.25	0.30 - 0.45	Poor
> 2.25	> 0.45	Very poor

Drain Spacing

The steady state drain spacing formula used in the irrigated areas is the Donnan formula (8).

$$S^2 = \frac{4k(H^2 - D^2)}{q} \qquad [9]$$

The second drain spacing equation which includes entrance resistance is the Ernst formula (1).

$$h = q\frac{S^2}{8kd} + qsre \qquad [10]$$

Where
- s = drain spacing (m)
- k = hydraulic conductivity of the soil (m day^{-1})
- d = distance between drain depth and impervious barrier (m)
- h = hydraulic head or water table elevation above drain level midway between the drains (m)
- H = h + d
- q = drain discharge rate per unit area (m day^{-1})
- kd = transmissivity (m^2 day^{-1})
- re = entrance resistance (days m^{-1})

Desalinization

Soil samples were collected from field 4c/6, 4c/7 and 4c/10A from the same sampling points to the survey of 1983 at the depth of 0–30, 30–60, 60–90 and 90–120 cm. Samples were air–dried and ground to pass through 2 mm sieve. Saturation extracts were obtained from saturated soil paste of soil samples and analyzed for pH, electrical conductivity (ECe), soluble anions and cations using standard analytical procedures. To compare existing salinity with the initial ones, the electrical conductivity of the soil samples was analyzed based on a 1:1 soil water suspension in 1983 and converted to electrical conductivity of saturation extract by equation developed in Melka Werer Research Center laboratory 1990 (table 6).

Table 6. Relationship between EC of soil water suspension and soil paste extraction

Soil water	R^2	Formulas
1:1	0.989	YECe = 0.48 + 1.28x
1:2	0.968	YECe = -1.11 + 2.99x
1:2.5	0.988	YECe = -0.38 + 2.75x
1:5	0.996	YECe = -0.45 + 5.71x

Where x = EC of soil: water suspension
Y ECe = EC of soil paste extraction

No variation was obtained for pH analyzed based on soil:water suspension and saturation extract.

RESULTS AND DISCUSSIONS

DRAIN LINE PERFORMANCE

Determination of hydraulic conductivity

The ratio of daily discharge and hydraulic head was computed for each tail recession periods. The regression line of q h^{-1} versus h was plotted on fig 3, 4 and 5.

Table 7. Average values of hydraulic conductivity derived from q h^{-1} - h relations

Recession period	Test drain line and envelope material	Spacing (m)	Hydraulic conductivity k (m day^{-1}) Hooghoudt K from A term	Hooghoudt K from B term	Boussinesq equation tan a	Boussinesq equation K (m day^{-1})
April-August 1984	3/Gravel	75	3.18	4.56	-	-
June-August 1989			1.66	7.45	$5.3x10^{-3}$	8.62
March-June 1984	8/Gravel	40	3.40	3.02	-	-
May- August 1989			3.53	4.05	$11.5x10^{-3}$	5.32
April-August 1984	18/Gravel	40	1.53	5.91	-	-
January-August 1989			5.78	5.75	$14.4x10^{-3}$	6.66
April-August 1984	21/red--ash	40	7.98	2.36	-	-
January-August 1989			7.88	4.47	$11.2x10^{-3}$	5.18

data for 1984 was taken from Halcrow (1986)

The relationship between drain discharge and piezometric head is a straight line. However, all drains showed a different gradient of the q h^{-1} versus h relationships (figs. 3,4 and 5). This was because of pedological variations resulted from the predominantly medium– or fine–textured stratified soils of alluvial origin of the pilot drainage scheme.

Based on measurement of discharge and hydraulic head, the mean values of hydraulic head computed using Hooghoudt equation were between 2 and 5 m day^{-1} and this allows a drain spacing of 50–60 meters at a depth of 2 m.

The q h^{-1} - h relationship of table 7, 8 and 9, Hooghoudt k Values from A and B terms showed that flow is taking place below and above drain levels respectively. The variability in the calculated values were the result of variability in pedological condition of the pilot drainage scheme. This confirms the result obtained by Halcrow, 1986.

Values of hydraulic conductivity derived from the hydraulic head–discharge analysis were similar to results obtained in 1984 by Halcrow. A series of monitoring results on the relationships between head and discharge by W. Halcrow (1986), Haider and Melkamu R. (1987) and the present result are similar. This indicates that the drains are functioning satisfactorily and the initial assumptions in the design criteria concerning the hydrological and pedological properties did not change.

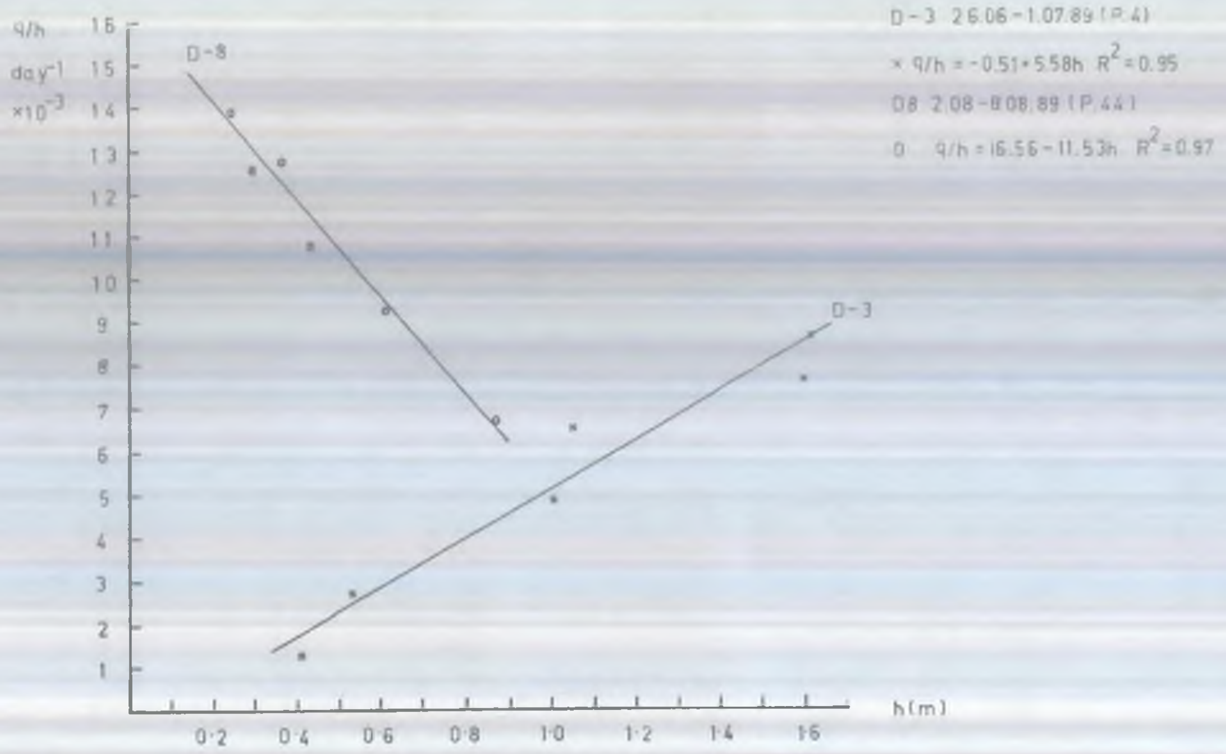

Figure 3. Plots of q h^{-1} versus h–Drain D–3 and D–8

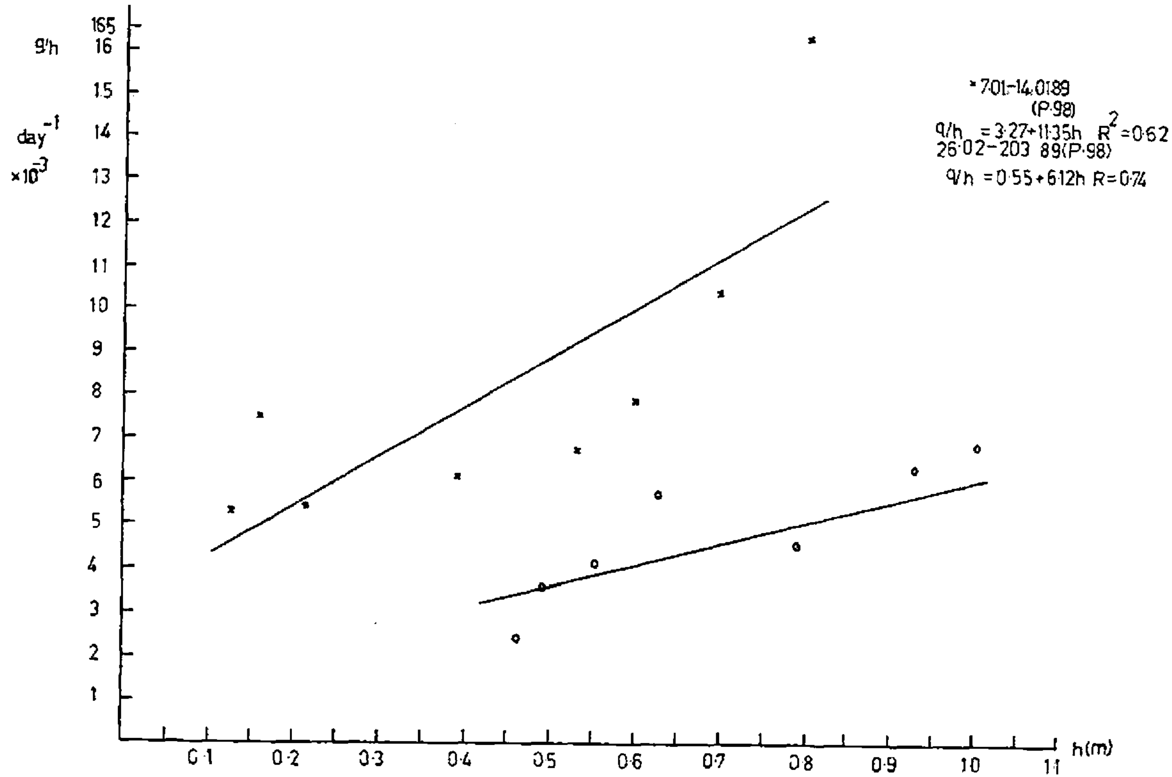

Figure 4. Plots of q h^{-1} versus h–Drain D–18

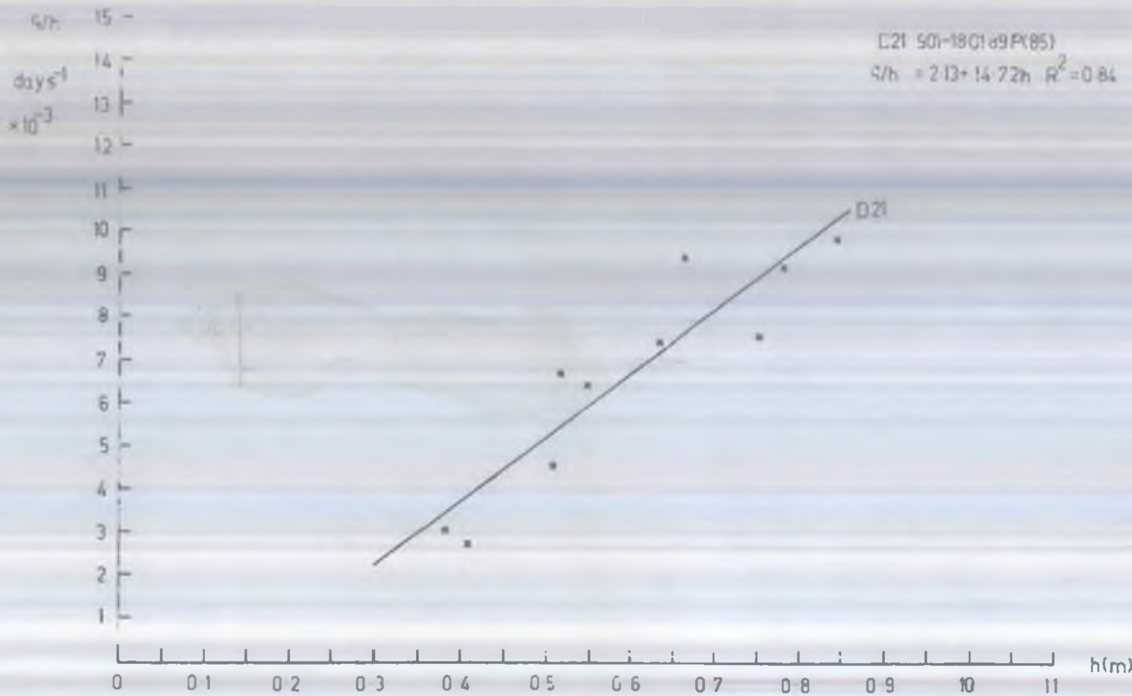

Figure 5. Plots of q h^{-1} versus h–Drain D–21

Table 8. Calculation procedure of discharge rates and corresponding hydraulic head for mid drain spacing piezometers

Drain number: D21
Recession period: 8/1/89 - 19/1/89
Drain length: 181 m

Piezometer number	Left	Right
Row I	85	82
Row II	107	99
Row III	124	121

		left-hand							right-hand					
Date (Jan.)	Discharge, q m day^{-1} x10^{-3}	h(m)	Row I q h^{-1} day^{-1}	day^{-1}	Row II q h^{-1} day^{-1}	day^{-1}	Row III q h^{-1} day^{-1}	day^{-1}	Row I q h^{-1} x10^{-3}	h(m)	Row II q h^{-1} x10^{-3}		Row III h(m)	q h^{-1} x10^{-3}
8	1	9.5	0.1	-	0.7	13.6	0.7	13.0	1.0	9.3	1.1	9.5	0.8	11.4
9	2	8.3	0.8	9.9	0.7	10.9	0.9	8.6	0.8	9.8	1.1	8.7	0.7	11.2
10	3	7.1	0.8	9.2	0.6	11.3	0.7	10.3	0.7	10.1	1.0	6.8	0.7	9.7
11	4	6.0	0.8	7.8	0.5	12.2	0.5	11.3	0.5	11.3	1.0	5.8	0.6	9.5
12	5	6.0	0.6	9.2	0.4	16.2	0.4	14.6	0.4	15.8	0.9	6.5	0.6	9.4
13	6	4.8	0.6	7.5	0.3	16.0	0.3	13.7	0.3	16.0	0.9	5.2	0.5	8.7
14	7	3.6	0.5	6.5	0.2	17.1	0.3	13.8	0.2	17.1	0.8	4.3	0.5	6.5
15	8	3.6	0.5	6.9	0.1	24.0	0.2	17.1	0.2	18.9	0.8	4.3	0.5	6.5
16	9	2.4	0.5	4.7	0.1	26.7	0.2	15.0	0.2	11.4	0.8	2.9	0.4	5.5
17	10	1.2	0.4	2.9	0.1	20.0	0.1	10.9	0.1	13.3	0.7	1.6	0.4	3.0
18	11	1.2	0.4	3.1	-	-	0.1	17.1	0.1	17.1	0.7	1.6	-	-
19	12	0.5	-	-	-	-	-	-	0.0	16.7	-	-	0.3	1.4

Linear Regression Equations

$$\frac{q}{h} = A + Bh$$

	Row I	$\frac{q}{h} = -2.13 + 14.72h$	$R^2 = 0.84$
LHS	Row II	$\frac{q}{h} = 23.53 - 17.92h$	$R^2 = 0.74$
	Row III	$\frac{q}{h} = 15.97 - 6.76h$	$R^2 = 0.51$
	Row I	$\frac{q}{h} = 17.06 - 8.11h$	$R^2 = 0.59$
RHS	Row II	$\frac{q}{h} = -11.23 + 17.84h$	$R^2 = 0.96$
	Row III	$\frac{q}{h} = -4.50 + 20.64h$	$R^2 = 0.90$

Determination of Entrance Resistance

The entrance resistance (re) and residual value (a) were calculated from the regression relationship of head loss (he) drain spacing (s) and drain outflow rate per unit area (q) and the regression lines are shown in figures 6, 7 and 8 and table 11.

The entrance resistance of the red-ash and gravel filter envelope materials (re_1) are smaller than 0.75 days m^{-1}. This shows that the performance of these lines are good throughout the testing years (table 5, 10 and 12). However, the entry resistance of the factory made filter material was in the order of ten fold greater than either gravel or red-ash filter materials. The value of entrance resistance for this material is greater than 2.25 days m^{-1}, in which according to FAO recommendation regarded as very poor performance (table 5). This is likely to be the result of settling, backfilling and / or clogging of the filter by fine materials.

The best combination of drainage materials is PVC pipe and red-ash envelope material(table 10)with a lowest entrance resistance (re_1 = 0.1 - 0.5 day m^{-1}). Corrugated PVC pipe and graded gravel envelope materials can also be used. However, the application of these combinations must be evaluated from the economic point of view. The data in table 10 indicate that the entrance resistance for red-ash envelope does not increase over time and the regression equation for 55 drainage events with time was developed as

$$re_1 = 0.01\ Ne - 0.01$$
$$R^2 = 0.18$$

Where Ne =number of events starting from 1986 to 1990 (1-55).

Frequently, values of residual head were very small showing that head measurement declines and close to zero after discharge ceases. Slightly higher values of residual head were observed on drain with factory made envelope material because water does not enter the drain due to high resistance of the envelope.

The entrance resistance due to trench disturbance (re_2) is to 0.3 and 5.0 days m^{-1} for the drains with red-ash and factory made envelope materials respectively (table 10). This is because the flow of water from the disturbed trench to the drain is restricted by the equi-potential media of the trench and the factory made filter which has high entrance resistance to inflowing water.

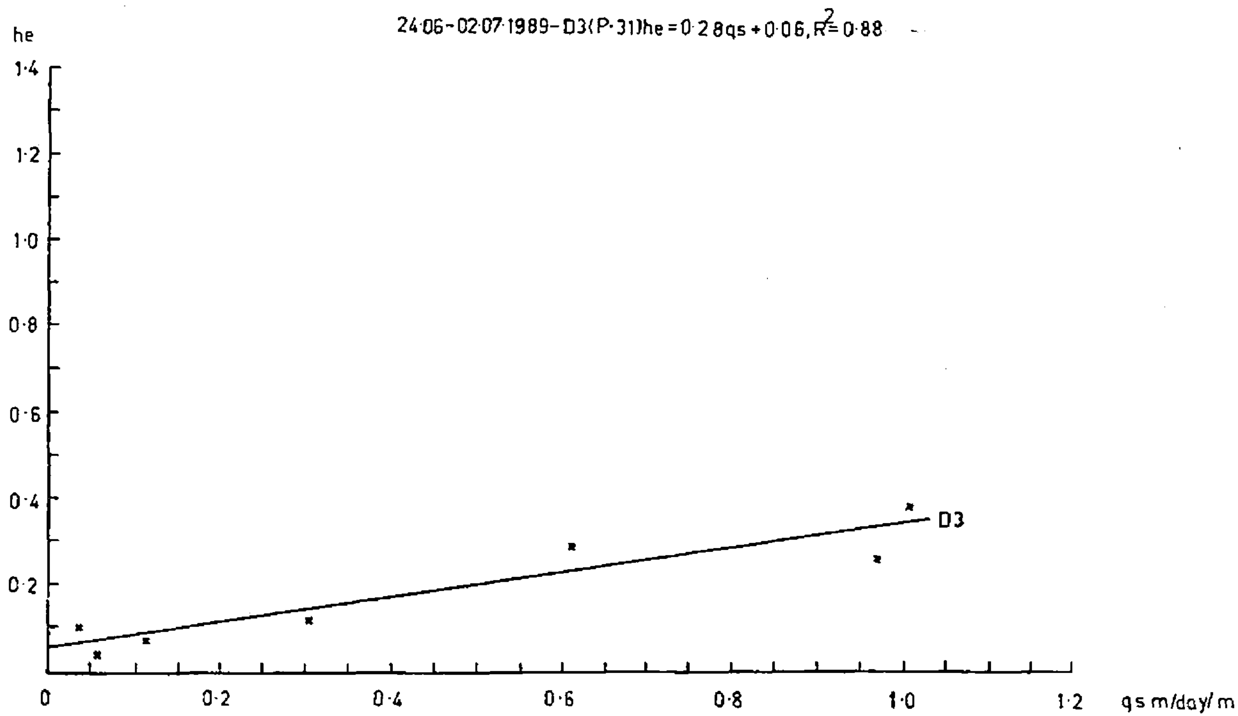

Figure 6. Entrance resistance of drain pipe with gravel envelope

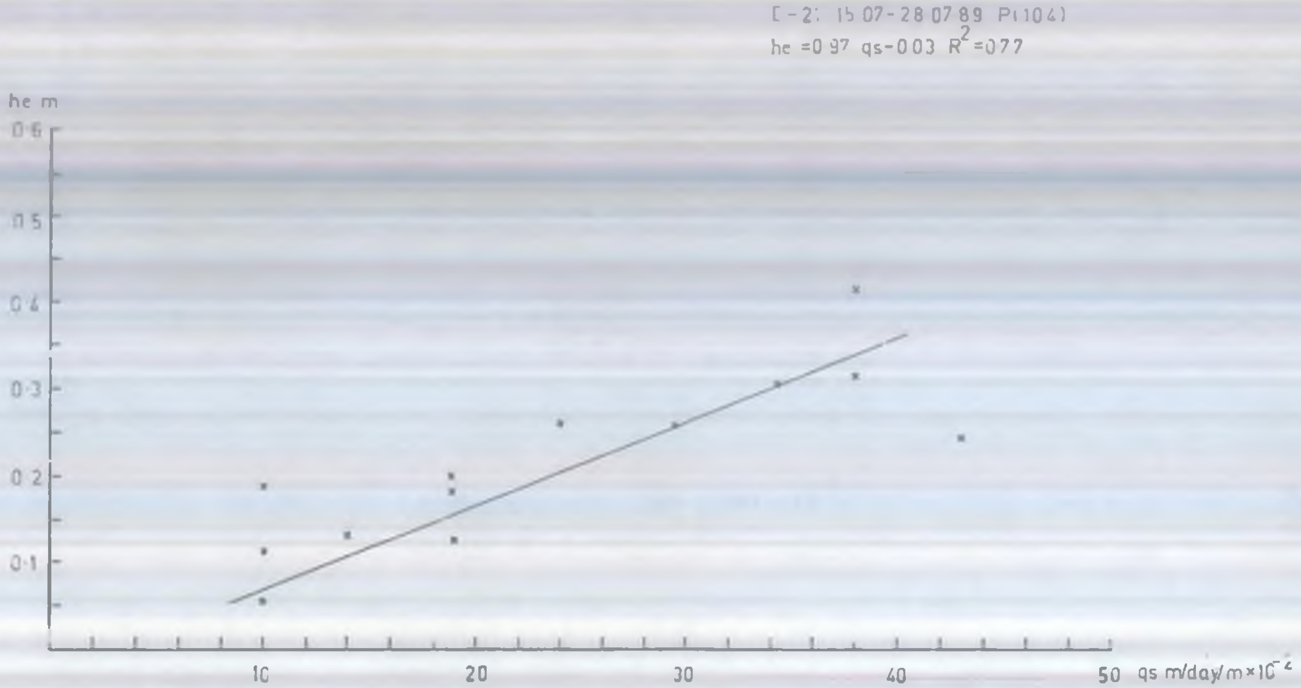

Figure 7. Entrance resistance of drain pipe with red–ash envelope, 1989

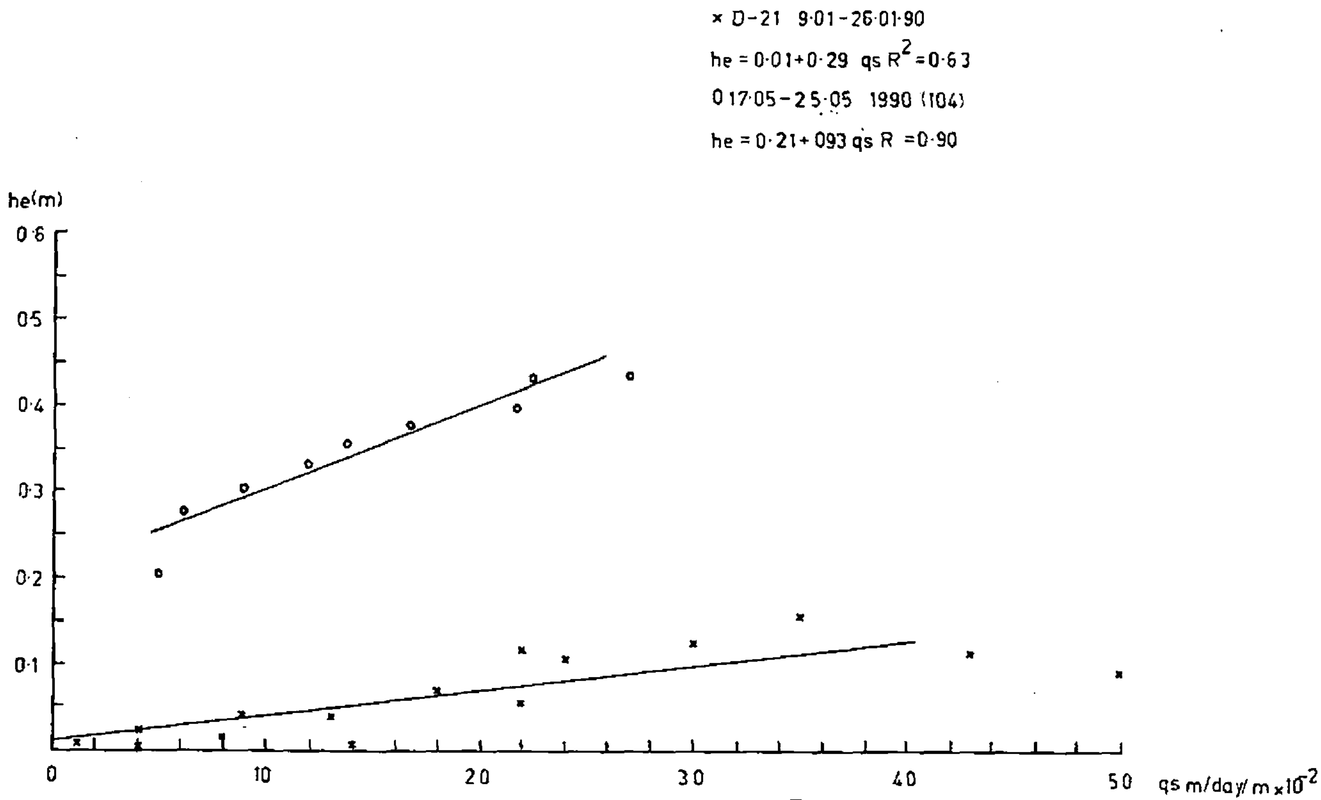

Figure 8. Entrance resistance of drain pipe with red–ash envelope, 1990

Table 9. Hydraulic conductivity derived from q h^{-1} - h relation

Tail recession period 1989/90	k from B term, $B = \frac{4k}{s^2}$ (m day^{-1}) LHS I	LHS II	LHS III	RHS I	RHS II	RHS III	kd from A term, $A = \frac{8kd}{s^2}$ (m^2 day^{-1}) LHS I	LHS II	LHS III	RHS I	RHS II	RHS III	calculated k (m d^{-1}) (kd) d = equivalent thickness LHS I	LHS II	LHS III	RHS I	RHS II	RHS III
Drain No. 3																		
28/6-1/7				7.9	8.3	8.2						1.2						0.5
14/8-18/8	8.1											8.8						2.8
Drain No. 6																		
28/5-12/6						10.0		2.1			3.1	7.4		1.9			2.8	8.8
30/6-18/7			2.7			1.1		2.8	1.1		2.9	1.8		2.5	0.9		2.6	1.8
1/8-7/8								3.3	4.5	7.6	5.2	10.9		3.0	4.0	6.8	4.7	9.7
19/8-30/8								2.0	3.3	3.0	2.3	4.0		1.8	3.0	2.7	2.0	3.6
Drain No. 18																		
7/1-14/1		4.5			12.4		2.7	0.7					5.5	1.3				1.0
4/2-13/2		1.5			3.4	7.2	3.8					0.9	7.8					
28/2-2/3		2.5					2.5						5.1					
13/3-21/3					2.2	3.6	4.1	1.8				1.5	6.3	3.8				1.7
2/4-9/4							11.7	1.1			7.6	8.2		2.2			15.5	9.1
21/4-28/4							3.4	1.5					7.0	3.0				
11/5-18/5		3.7			8.8		3.4						6.9					
1/6-7/6		4.6		6.3	16.4		2.8			1.2			5.2			2.5		
22/6-28/6		1.8					2.7				6.5		5.5				17.3	
14/7-23/7		1.1	3.2		5.7		4.4					1.8	9.0					1.8
2/8-10/8		8.7			13.9	5.2	2.9					1.6	5.9					1.8
Drain No. 21																		
8/1-18/1	5.8				7.1	8.3		4.7	3.2	3.4				9.6	6.5	7.0		
2/2-17/2					4.0	4.1	13.5	9.9	3.4	4.0					6.9	8.2		
1/3-8/3	5.3				4.8	4.8		12.4	5.5	4.6		1.0			6.5	9.5		2.1
17/3-28/3					19.4		6.1	4.9	3.2	3.1		4.5	12.4	10.0	6.5	8.3		9.2
1/4-9/4						3.2	9.3	8.9	4.1	6.2	2.3			14.2	6.4	10.8	4.6	
10/4-19/4					2.1	0.9	9.7	7.8	4.3	6.3				16.0	6.7	12.8		
20/4-27/4	4.0				1.8			2.3	2.2	2.2		2.0		4.5	4.5	4.5		4.0
11/5-18/5					3.3	3.7	3.7	6.2	2.2	2.3			7.5	12.6	4.4	4.7		
2/6-11/6							6.1	4.2	2.9			2.9	12.4	8.5	5.9			6.0
22/6-6/7					7.5	8.2	5.3	6.1	2.2				10.9	12.4	4.5			
14/7-1/8					2.9	0.5	5.6	4.2	2.7			2.0	11.5	8.6	5.5			4.0
4/8-28/8					1.2		5.8	3.5	2.8	2.2		2.5	11.9	7.1	5.3	4.5		5.0

Table 10. Average values of entrance resistance (re) and residual values (a) of the test drain

Drain No.	Period	No. of events	re (days m^{-1})	a (m)	re (days m^{-1})	a (m)	Envelope material
3	1984*	6	0.63	0.09	0.23	0.10	Gravel
	1989	2	0.35	0.09	0.36	0.25	60 mm pipe
21	1984*	6	0.35	0.05	0.09	0.23	
	1986	3	0.08	0.16	0.14	0.12	Red ash
	1987	13	0.11	0.17	0.32	0.14	60 mm pipe
	1988	18	0.21	0.08	0.26	0.05	
	1989	16	0.53	0.07	0.41	0.06	
	1990	7	0.22	0.08	0.23	0.07	
24	1984*	6	4.62	0.30	0.00	0.12	factory made filter
	1986	1	4.63	0.38	6.24	0.19	
	1987	6	5.77	0.72	5.51	0.37	60 mm pipe

* Halcrow (1986)

Table 11. Calculation procedure of the entrance resistance re_1 due to envelope and re_2 due to trench disturbance

Drain No. 21
Drain spacing S = 40 m
Drain length L = 181 m

Piezometer numbers
105 / 104 / 103 / 102 / 101
meters from drain center line
1.0 / 0.3 / 0 / 0.3 / 1.0

Date	Discharge q (m day^{-1} x10^{-3})	q.s (m^2 day^{-1})	LHS he_2(m)	LHS he_1(m)	RHS he_1(m)	RHS he_2(m)
9/1	4.18	0.17	-0.45	-0.26	-0.05	-0.08
10/1	12.50	0.50	-0.67	0.09	0.15	0.16
11/1	10.74	0.43	0.34	0.12	0.02	0.06
12/1	8.83	0.35	0.17	0.16	0.08	0.06
13/1	7.40	0.30	0.21	0.13	0.10	0.05
14/1	5.97	0.24	0.24	0.11	0.09	0.05
15/1	5.37	0.22	0.24	0.12	0.09	0.05
16/1	5.01	0.22	0.17	0.06	0.03	0.03
17/1	4.42	0.18	0.17	0.07	0.03	0.04
18/1	3.46	0.14	0.10	0.01	-0.01	0.02
19/1	3.22	0.13	0.12	0.04	0.02	0.03
20/1	2.27	0.09	0.11	0.04	0.02	0.03
21/1	2.51	0.10	0.08	0.01	0.01	0.03
22/1	2.03	0.08	0.25	0.02	0.00	0.03
23/1	1.91	0.08	0.02	0.01	-0.02	0.02
24/1	1.07	0.04	0.03	0.00	-0.01	0.02
25/1	1.07	0.04	-0.01	-0.10	-0.02	0.03
26/1	0.96	0.04	0.04	0.03	0.03	0.06

$$he = a + re\, q.s$$

LHS $he_1 = 0.01 + 0.29\ qs$ $R^2 = 0.63$

LHS $he_2 = 0.05 + 0.61\ qs$ $R^2 = 0.59$

RHS $he_1 = 0.01 + 0.21\ qs$ $R^2 = 0.44$

RHS $he_2 = 0.01 + 0.18\ qs$ $R^2 = 0.58$

Table 12. Drain line performance - entrance resistance

Tail recession period	Entrance resistance Re_1 LHS	Re_1 RHS	Re_2 LHS	Re_2 RHS	Residual values e_1 LHS	e_1 RHS	e_2 LHS	e_2 RHS	Correlation coefficient R_1^2 LHS	R_1^2 RHS	R_2^2 LHS	R_2^2 RHS
1989						.... Drain No.3						
24/6-2/7	0.28	0.38	0.28	0.65	0.06	0.03	0.03	0.10	0.88	0.70	0.74	0.75
14/8-19/8	0.38	0.36	0.27	0.22	0.13	0.13	0.68	0.17	0.63	0.55	0.92	0.56
1986/87						.... Drain No. 24						
12/12-22/12	6.59	3.06	6.69	5.79	0.14	0.62	0.16	0.22	0.86	0.23	0.85	0.86
4/1-19/1	1.74	1.86	1.75	1.12	0.38	0.72	0.38	0.57	0.07	0.08	0.06	0.12
9/7-24/7	4.82	4.71	5.04	4.56	0.22	0.23	0.24	0.25	0.38	0.37	0.35	0.40
2/9-17/9	7.14	6.74	7.31	7.25	0.19	0.26	[illegible]	0.16	0.59	0.60	0.60	0.64
5/10-26/10	6.39	5.43	5.82	6.10	0.39	0.48	0.54	0.48	0.75	0.62	0.46	0.70
3/11-16/11	4.58	6.66	4.25	0	0.56	0.52	0.81	0.64	0.35	0.22	0.26	0.03
1986/87						.... Drain No. 21						
10/12-24/12	0.16	0.15	0.34	0.17	0.16	0.01	0.09	0.05	0.04	0.12	0.10	0.20
24/12-6/1	0.00	0.00	0.00	0.05	0.42	0.13	0.25	0.09	0.57	0.04	0.35	0.04
8/1-21/1	0.00	0.04	0.00	0.12	0.27	0.03	0.21	0.06	0.46	0.08	0.52	0.40
13/2-27/2	0.03	0.00	-	0.29	0.01	0.10	[illegible]	0.01	0.38	0.10	-	0.70
11/3-31	0.00	0.22	-	0.32	0.02	0.04	[illegible]	0.01	0.039	0.27	-	0.88
6/7-31/7	0.0019	-	0.08	0.03	0.01	-	0.21	0.03	0.021	-	0.002	0.92
1/9-19/9	0.00	0.00	0.29	0.24	0.03	0.45	0.33	0.01	0.09	0.01	0.07	0.31
18/11-8/12	0.03	0.00	0.00	0.00	0.01	0.11	0.15	0.18	0.12	0.0023	0.00002	0.05
9/12-21/12	0.13	0.32	0.26	2.73	-0.00049	0.05	0.06	-0.21	0.17	0.22	0.08	0.59
2/12-3/1	0.10	0.08	0.17	0.58	0.0045	0.07	0.02	0.01	0.57	0.02	0.11	0.18
1988/89												
6/1-23/1	0.04	0.14	0.19	0.32	0.01	0.16	0.14	0.01	0.24	0.02	0.02	0.95
24/1-7/2	0.07	0.00	0.00	0.24	0.01	0.12	0.08	0.02	0.28	0.02	0	0.67
1/3-14/3	0.10	0.38	-	0.05	0.004	0.04	[illegible]	0.05	0.25	0.19	-	0.03
5/4-15/4	0.00	0.00	0.00	0.06	0.06	0.33	0.21	0.07	0.02	0.57	0.14	0.04
17/4-27/4	0.00	0.00	0.00	0.70	0.03	0.07	0.08	-0.01	0.01	0.01	0.35	0.33
5/5-14/5	0.10	0.00	0.00	0.38	0.02	0.26	0.12	0.002	0.15	0.30	0.19	0.78
14/5-25/5	0.03	0.00	0.00	0.18	0.03	0.27	0.16	0.03	0.01	0.35	0.17	0.41
26/5-9/6	0.00	0.29	0.92	1.17	0.03	0.11	0.07	-0.10	0.0018	0.09	0.37	0.36
10/6-10/6	0.17	0.23	0.28	0.40	0.002	0.05	0.03	0.01	0.76	0.09	0.03	0.68
21/6-1/7	0.17	0.12	-	0.30	0.02	0.07		0.01	0.22	0.05	-	0.75
2/7-23/7	1.46	0.00	0.00	0.25	-0.02	0.20	0.22	0.03	0.07	0.08	0.50	0.52
7/9-24/9	0.60	0.10	0.42	0.10	-0.04	0.01	0.03	0.04	0.59	0.14	0.27	0.20
26/9-10/10	0.13	0.10	0.33	0.31	0.01	0.28	0.07	0.01	0.38	0.02	0.19	0.74
24/10-7/11	0.20	0.57	0.00	0.41	0.04	0.05	0.10	0.02	0.14	0.45	0.01	0.55
12/12-31/12	0.59	0.40	0.44	0.21	-0.04	0.21	0.04	0.04	0.72	0.12	0.53	0.14
4/2-17/2	0.99	0.90	0.01	0.45	-0.05	-0.003	0.09	0.01	0.80	0.75	0.01	0.87
1/3-9/3	0.96	0.85	0.55	0.27	0.02	0.02	0.08	0.03	0.67	0.87	0.57	0.81
18/3-29/3	0.09	0.52	0.00	0.21	0.13	0.07	0.36	0.04	0.04	0.85	0.63	0.86
1/4-9/4	0.00	0.31	0.00	0.00	0.24	0.19	0.14	0.13	0.50	0.68	0.03	0.25
10/4-18/4	0.33	0.64	0.37	1.47	0.01	-0.04	0.01	-0.01	0.03	0.10	0.13	0.08
20/4-27/4	0.28	0.75	-	0.30	-0.03	0.16		0.07	0.73	0.16	-	0.07
1/6-12/6	0.00	0.00	0.00	0.26	0.15	0.10	0.28	0.02	0.07	0.01	0.03	0.46
22/6-8/7	1.11	0.26	0.44	0.31	0.01	0.43	0.19	0.01	0.75	0.06	0.23	0.76
14/7-1/8	0.97	0.32	0.66	0.55	-0.03	0.47	0.10	0.02	0.77	0.08	0.50	0.35
2/8-23/8	0.70	1.19	0.70	0.39	-0.08	0.13	0.01	0.03	0.41	0.37	0.47	0.10
7/9-26/9	0.08	0.37	0.53	0.14	0.02	0.04	0.04	0.01	0.21	0.65	0.42	0.66
25/11-9/11	0.57	0.16	0.22	0.24	-0.01	0.02	0.10	0.01	0.78	0.46	0.09	0.28
9/1-26/2/9	0.29	0.21	0.61	0.18	0.01	0.01	0.05	0.01	0.63	0.44	0.59	0.58
7/2-22/2	0.00	0.00	0.00	0.22	0.05	0.03	0.06	0.05	0.04	0.00	0.02	0.02
23/2-21/3	0.21	0.11	0.00	0.19	0.01	0.03	0.09	0.01	0.08	0.02	0.10	0.12
22/3-13/4	0.12	0.53	0.49	0.35	0.03	-0.01	0.01	0.003	0.08	0.37	0.49	0.43
24/4-9/5	-	0.23	0.23	0.03	-	0.41	0.03	0.01	-	0.07	0.21	0.01
17/5-25/5	0.93	0.18	0.63	0.22	0.21	0.02	0.02	0.02	0.90	0.53	0.80	0.53

DRAIN SPACING FOR DIFFERENT FILTER MATERIALS

Drain spacing was calculated using drainage criteria adopted from Melka Sedi pilot scheme.

- Average value of measured hydraulic conductivity k = 2.0 m day^{-1};
- Surveyed data of impervious layer is at the depth of 2.5 m below ground surface (Halcrow, 1986);
- Minimum depth to water table = 1.3 m for drain at 2.0 m depth, thus h = 0.7 m;
- Hydraulic head + impervious barrier;

$$H = h + D = 0.7 + 0.5 = 1.2\ m$$
$$D = 2.5 - 2.0\ m = 0.5\ m$$

- In field percolation to drainage system, assumed 25% of gross field application of 100 mm of water with 14 days of interval. Substituting the above drainage design factors to the Donnan's and Ernst's formula equation 9 and 10.

$$Discharge = q = \frac{25\ mm}{14\ days} = \frac{0.025\ m}{14\ days} = 0.002\ m\ day^{-1}$$

$$S2 = \frac{4k(H^2 - D^2)}{q}$$

$$S^2 = \frac{4x2(1.2^2 - 0.5^2)}{0.002\ m\ day^{-1}}$$

$$S^2 = \frac{8(1.44-0.25)}{}$$

$$0.002\ m\ day^{-1}$$

$$S^2 = 4760.0\ m^2$$

$$S = 69.0\ m$$

A similar calculation using the Ernst's equation 10.

$$h = q\frac{S^2}{8kD} = qsre$$

$$0.7 = \frac{0.002\ S^2}{8x2x0.5} + 0.002\ x\ S\ x\ re$$

The relationship can be simplified as

$$S^2 + 8sre - 2800 = 0$$

This equation was used to calculate drain spacing for different filter materials with varying values of entrance resistance.

Table 13. Relation between entrance resistance and drain spacing according to the Ernst formula

Test drain lines	Envelope material	Entrance resistance re (day m^{-1})	Established drain spacing(m)
3	Gravel	0.6	50.6
		1.0	49.1
21	Red ash	0.1	52.5
		0.2	52.0
		0.6	50.6
		1.5	47.1
24	Factory made filter	4.6	37.6
		5.8	34.6

Table 13 showed the results derived for different values of entrance resistance (re). The results revealed that if drainage and filter materials of high entrance resistance are used the drain spacing will be reduced. This, thus, confirmed that the drain spacing in between

50 and 60 meters can be foreseen for subsurface drains using either red ash or gravel as pipe surround.

Desalinization Process

Field 4c/6 (75–meters drain spacing)

Analytical results of the soil survey of 1983 revealed that soils of this field were saline to saline–sodic, with an ECe value ranging from 4.6 to 51 ds m^{-1} (7). These results were almost in agreement with the analytical data from pit ECe values ranging from 11.0 to 59.3 ds m^{-1}.

Salinity amelioration was monitored in 1989 and 1990 from auger hole samples collected approximately from the same site of 1983 survey. Soils of these area were saline to saline-sodic after four successive cropping seasons (table 14). ECe values varied from 2.1 to 29.0 ds m^{-1} on bare soils. However, the salt concentration was tremendously reduced as a function of leaching on 86 % of sampling spots, while few build–ups were also recorded in 1989. The direction of salt movement in the profile was rather controversial in few sites.

According to the analytical results of 1990, soils of this field remained saline and saline-sodic (table 14). ECe values and ESP varies from 0.4 to 36.6 ds m^{-1} and 0.5 to 42.5 respectively. However, 49% of the observation spots were reclaimed, while on the remaining points a tremendous salt disposal was recorded, except on A09 where it remained still saline and saline–sodic.

More salt accumulation was observed at 0–30 cm soil layer than lower soil profiles. This indicates the movement of salt upwards up on drying due to irregular land levelling or wide drain spacings (75 m) to intercept excess moisture below root zone.

More soluble sodium,i.e., from 1.09 to 157.29 me l^{-1} was obtained at 0–30 cm soil depth. Calcium also followed the trend of sodium, where concentrations are increasing toward the soil surface and in general varies from 2.00 to 198.78 me/l. The ratio of Ca + Mg to Na is high enough to counteract the effect exerted by sodium. In some sampling sites soluble magnesium values are trace, while in few areas abnormally high values were recorded (Appendix 1).

Bicarbonate concentrations (HCO_3^-) in the soil are fairly low. It must be noted that HCO_3^- plays an important role between calcium and sodium. That is the increase in the exchangeable sodium in soils as the result of high bicarbonate concentration in irrigation water or soils was partially attributed to the precipitation of the soluble and exchangeable calcium as calcium carbonate, thus resulting in the accumulation of sodium in the soil exchange complex. However, in the pilot drainage scheme, the contribution of bicarbonates to the precipitations calcium is minimum.

Chloride (cl-) concentration in the drainage scheme soil is not high relatively. Chloride doesn't precipitate, adsorbed or react with soil and doesn't exert any harmful effect on either soil structure or texture. Therefore, it moves readily with the soil water, taken up by crops, moves in the transpiration stream and accumulates in the leaves. As the chloride concentration exceeds the tolerance of the crop, injury symptoms develop, such as leaf burn or drying of leaf tissues. Hence, since such injury symptoms were not observed, the concentration of chloride in the soil must be with in the tolerance threshold limits of the crop, mainly cotton.

Table 14. pH, electrical conductivity and ESP of soils field 4c/6, 75 meters drain spacing

Sampling point	Soil depth (cm)	1983 pH	1983 ECe (ds m⁻¹)	1989 pH	1989 ECe (ds m⁻¹)	1989 ESP	1990 pH	1990 ECe (ds m⁻¹)	1990 ESP
A01	0-30	7.6	18.5	-	-	-	8.3	15.0	42.5
	30-60	7.4	8.7	-	-	-	8.1	5.9	11.2
	60-90	7.3	4.6	-	-	-	7.8	5.2	20.1
	90-120	7.8	4.8	-	-	-	8.1	0.4	0.8
A02	0-30	7.3	35.6	7.8	6.7	6.7	7.9	3.9	3.3
	30-60	7.4	18.5	7.9	5.8	7.7	7.6	3.2	2.1
	60-90	7.3	16.0	8.0	6.9	10.3	7.9	3.3	7.8
	90-120	7.5	14.4	6.0	8.3	11.4	7.8	3.2	8.3
A03	0-30	7.3	26.7	8.2	2.1	6.5	8.4	1.2	3.3
	30-60	7.2	22.7	8.0	2.1	6.5	8.2	0.8	5.6
	60-90	7.2	22.7	6.9	3.5	3.1	8.1	0.9	6.4
	90-120	7.2	16.5	7.9	3.3	1.7	8.3	0.9	5.4
A04	0-30	7.3	19.6	7.9	15.0	20.2	7.4	26.6	9.7
	30-60	7.2	14.4	7.9	10.8	15.2	7.2	18.1	7.9
	60-90	7.2	13.9	7.9	7.6	23.7	7.6	0.4	-
	90-120	7.2	13.9	8.5	7.1	35.7	7.2	13.7	0.7
A08	0-30	7.9	21.6	-	-	-	8.2	13.1	27.2
	30-60	6.0	9.2	-	-	-	8.0	6.8	13.9
	60-90	8.0	9.2	-	-	-	7.9	12.9	30.3
	90-120	6.0	8.2	-	-	-	7.9	4.3	5.3
A09	0-30	7.7	15.4	7.6	27.7	16.8	7.8	27.2	16.9
	30-60	7.7	15.4	7.7	17.3	21.4	7.7	18.1	11.0
	60-90	7.7	15.4	7.6	12.0	23.3	7.8	16.6	13.6
	90-120	7.8	12.3	7.5	18.0	22.3	7.4	18.4	18.5
A10	0-30	7.4	51.4	7.8	5.7	6.2	7.3	36.6	12.0
	30-60	7.7	22.7	7.6	6.1	5.9	7.5	17.7	18.6
	60-90	7.7	22.7	7.7	6.1	8.7	7.5	18.5	19.7
	90-120	7.5	24.2	7.7	7.3	12.0	7.7	16.9	-
A011	0-30	7.5	45.2	7.1	23.5	14.8	7.5	5.6	6.4
	30-60	7.5	45.2	7.1	17.0	14.5	7.6	4.5	3.0
	60-90	7.6	23.7	7.6	16.0	14.7	7.9	2.6	2.1
	90-120	7.6	20.0	8.0	13.8	20.0	8.0	2.4	1.6
A015	0-30	7.4	31.9	-	-	-	8.0	0.8	2.4
	30-60	7.9	7.1	-	-	-	8.2	0.7	0.5
	60-90	7.9	7.1	-	-	-	7.9	5.1	7.5
	90-120	7.9	7.1	-	-	-	8.0	6.5	12.8
A016	0-30	7.6	25.8	7.9	29.0	16.5	7.9	5.3	4.6
	30-60	7.6	25.8	7.2	25.0	16.9	8.0	4.2	4.9
	60-90	7.7	17.5	7.5	15.0	17.8	7.8	5.4	5.8
	90-120	7.7	17.5	7.4	16.0	19.0	7.8	6.9	11.3
A017	0-30	7.2	37.1	7.8	2.1	4.7	8.1	1.4	2.0
	30-60	7.2	37.1	8.0	4.0	5.1	7.5	7.3	4.3
	60-90	7.2	12.3	7.4	3.6	6.4	7.7	3.2	1.6
	90-120	7.6	12.3	7.2	4.1	8.8	7.5	10.7	9.8
A018	0-30	7.4	42.1	7.3	16.0	10.9	8.0	0.9	0.9
	30-60	7.4	42.1	7.2	18.0	12.7	7.8	0.6	1.2
	60-90	7.4	29.8	7.2	15.0	20.2	7.9	0.4	-
	90-120	7.6	29.8	7.3	16.0	11.7	7.7	0.6	1.0

- not analyzed

Field 4c/7 (20– and 40– meters spacings)

According to Halcrow (1986), soils of the area are considered non saline and non–sodic.This result was based on samples taken from soil pit dug at right end of the field, which was not a good representative of the site because salinity is variable. On the other hand, the analytical result of 36 soil samples collected from nine points of this field at in 1983 indicated that soils of this field were saline with an electrical conductivity of greater than 4 ds m^{-1} (table 15).

After the establishment of the scheme and successive cropping of cotton since 1986, about 62% of the soil samples collected in 1989 approximately from the same points of survey of 1983, had an EC value greater than 4 ds m^{-1}. On this field, about 38% was only reclaimed from salinity. This was mainly due to the head losses in drain collector (co1), where drains are submerged and no disposal of water from the field. Salinity profile increases with depth. This shows the tendency of salt movement toward the lateral drain and conventionally disposable under functional system cases.

In 1990, auger hole samples were collected from the same site to that of 1983 and 1989. The top soils of this field are now 100% reclaimed, after five successive cropping seasons (table 15 and Appendix 2). But, a few sites at lower depths remain saline (A012, A013, A05, A020), which is most likely due to the blockage of lateral drain so that excess water disposal toward the collector drain was not efficient enough to carry salts.

Table 15. pH, electrical conductivity and ESP of soils field 4c/7 20-40 meters drain spacing

Sampling point	Soil depth (cm)	1983 pH	1983 ECe (ds m^{-1})	1989 pH	1989 ECe (ds m^{-1})	1989 ESP	1990 pH	1990 ECe (ds m^{-1})	1990 ESP
A05	0-30	7.9	4.7	7.7	1.1	2.3	7.9	1.4	2.5
	30-60	7.8	4.7	7.8	0.7	2.7	7.9	1.1	3.8
	60-90	7.8	4.2	7.6	0.4	2.0	7.6	4.2	1.4
	90-120	7.8	4.2	7.6	0.9	2.1	7.9	0.7	3.6
A06	0-30	7.7	4.0	-	-	-	7.8	0.7	1.1
	30-60	7.8	5.6	-	-	-	7.3	0.6	2.1
	60-90	7.8	5.6	-	-	-	8.0	0.6	2.6
	90-120	7.8	7.1	-	-	-	8.0	0.6	1.9
A07	0-30	7.7	5.2	7.8	1.4	11.8	8.0	0.6	2.2
	30-60	7.8	5.2	7.8	1.2	18.3	8.1	0.5	1.4
	60-90	7.8	4.5	7.7	4.0	12.3	8.2	0.5	2.6
	90-120	7.8	4.9	7.3	6.3	9.4	7.9	0.4	2.4
A012	0-30	7.7	4.9	7.7	2.8	2.6	8.2	1.1	1.6
	30-60	7.7	5.6	7.6	3.4	2.1	8.1	1.0	1.6
	60-90	7.7	5.6	7.7	4.1	3.4	7.6	4.5	2.9
	90-120	7.6	7.1	8.0	4.2	5.4	7.5	9.8	4.8
A013	0-30	7.7	4.5	-	-	-	8.1	1.1	1.8
	30-60	7.7	4.5	-	-	-	8.2	3.6	4.7
	60-90	7.7	4.5	-	-	-	7.9	4.8	6.8
	90-120	7.7	4.5	-	-	-	7.9	5.7	9.1
A014	0-30	7.7	11.3	7.4	5.3	4.5	7.6	0.5	1.1
	30-60	7.7	11.3	7.3	7.1	5.5	7.1	1.2	[illegible]
	60-90	7.7	11.9	7.4	15.9	10.9	7.9	0.9	2.4
	90-120	7.7	11.9	7.6	14.2	12.6	8.1	0.8	3.7
A019	0-30	7.8	5.2	8.1	5.1	11.8	7.9	0.5	0.1
	30-60	7.7	6.2	7.5	7.5	8.6	7.8	0.4	0.3
	60-90	7.7	7.1	7.5	8.5	9.6	7.9	0.4	4.8
	90-120	7.7	7.1	7.2	8.0	11.6	7.8	0.3	0.9
A020	0-30	7.6	4.3	-	-	-	7.8	0.9	1.7
	30-60	7.6	3.9	-	-	-	7.5	2.2	2.1
	60-90	7.6	3.5	-	-	-	7.6	3.5	5.5
	90-120	7.6	3.9	-	-	-	7.5	4.3	7.1
A021	0-30	7.7	4.2	7.8	1.6	1.5	8.0	1.2	2.6
	30-60	7.6	4.2	7.8	3.5	2.5	7.9	2.9	2.8
	60-90	7.6	4.2	7.7	4.6	3.6	7.8	2.3	2.7
	90-120	7.6	4.2	7.4	3.9	2.9	7.7	2.4	1.8

Field 4c/10A (different filter materials)

The survey result of 1983 regarded this field as a field that cannot produce due to its high salt content, mainly concentrated in the upper 30 cm soil layer. It was also reported as saline–sodic by Halcrow. 1986. However, after the establishment of the drainage scheme and plantation of banana crops in 1987, the analytical results of soil samples collected in 1989 showed that, the total salt concentration was reduced by 96% and the highest ECe and ESP recorded were 2.8 ds m^{-1} and 3.15 respectively (table 16). This result was also again confirmed by the analytical data derived from the same site in 1990, where this field is fully reclaimed (Appendix 3). Such a complete reclamation of this banana field was attributed to salt leaching from surface soil layer down wards due to continuous irrigation as compared to cotton fields (4c/6 and 4c/7) which were under seasonal irrigation.

Table 16. pH, electrical conductivity and ESP of soils field 4c/10A

		1983		1989			1990		
Sampling point	Soil depth (cm)	pH	ECe (ds m^{-1})	pH	ECe (ds m^{-1})	ESP	pH	ECe (ds m^{-1})	ESP
A022	0-30	7.7	26.2	8.0	0.6	0.7	8.1	0.5	1.1
	30-60	7.8	16.6	7.9	0.5	0.6	8.1	0.7	1.7
	60-90	7.8	12.9	7.7	0.8	0.3	8.1	0.3	0.6
	90-120	7.8	9.2	7.6	0.5	-	8.2	0.5	2.8
A023	0-30	7.2	5.2	7.8	0.7	2.9	7.5	0.9	2.0
	30-60	7.6	18.1	8.0	2.3	1.7	8.0	0.5	1.6
	60-90	7.6	18.1	7.8	0.4	0.3	7.9	0.4	1.1
	90-120	7.8	10.4	7.6	0.5	0.3	7.8	0.6	1.2
A024	0-30	7.2	48.3	8.1	2.4	-	8.2	0.5	0.7
	30-60	7.5	27.7	7.9	2.2	-	8.1	0.4	1.1
	60-90	7.5	30.8	8.3	1.3	-	8.2	0.4	0.7
	90-120	7.6	25.2	7.8	1.2	-	7.9	0.3	0.4
A025	0-30	7.4	61.7	8.1	0.5	0.5	8.1	0.5	0.8
	30-60	7.6	39.4	8.0	0.4	0.4	8.2	0.7	1.3
	60-90	7.6	25.8	8.0	0.3	-	7.8	0.4	1.0
	90-120	7.6	21.6	7.8	0.6	0.3	7.9	0.6	1.7
A026	0-30	7.5	20.6	7.8	1.1	2.2	7.9	1.1	1.6
	30-60	7.7	15.4	7.5	1.3	0.9	8.1	0.5	1.9
	60-90	7.7	15.4	7.6	1.7	-	8.1	0.6	5.3
	90-120	7.6	17.5	7.6	1.1	-	8.1	0.5	1.4
A027	0-30	7.2	56.0	8.2	0.6	1.2	7.7	1.1	1.8
	30-60	7.6	42.0	8.1	0.5	0.4	7.8	0.9	5.1
	60-90	7.6	42.0	7.9	0.4	0.1	7.7	0.3	0.6
	90-120	8.0	15.4	8.3	0.5	2.2	7.6	0.6	2.9
A028	0-30	7.0	23.3	8.5	0.5	1.1	7.8	0.4	0.6
	30-60	7.6	23.7	7.4	0.4	1.3	8.1	0.4	0.2
	60-90	7.6	11.3	7.9	0.7	0.2	8.0	0.4	0.1
	90-120	8.0	9.8	7.9	0.5	-	7.5	0.4	0.1
A029	0-30	7.0	51.4	7.9	0.9	1.1	8.0	0.5	1.4
	30-60	7.0	31.9	7.9	2.8	0.2	8.2	0.4	1.6
	60-90	7.4	31.9	7.7	2.3	-	7.8	0.3	0.7
	90-120	7.4	21.6	7.7	1.3	0.1	8.6	0.7	3.6
A030	0-30	7.7	21.6	7.0	8.0	2.5	8.0	0.6	0.8
	30-60	7.7	21.6	7.2	8.0	0.5	7.8	2.3	0.9
	60-90	7.2	21.6	7.2	7.8	-	7.7	3.0	1.0
	90-120	7.3	20.6	7.3	7.8	3.1	7.6	2.6	0.2
A031	0-30	7.0	34.6	7.0	-	-	8.1	0.9	0.5
	30-60	7.0	34.0	7.0	-	-	7.7	2.8	1.5
	60-90	7.2	23.7	7.2	-	-	7.7	3.2	1.4
	90-120	7.5	21.6	7.2	-	-	7.6	2.8	-

- not analyzed

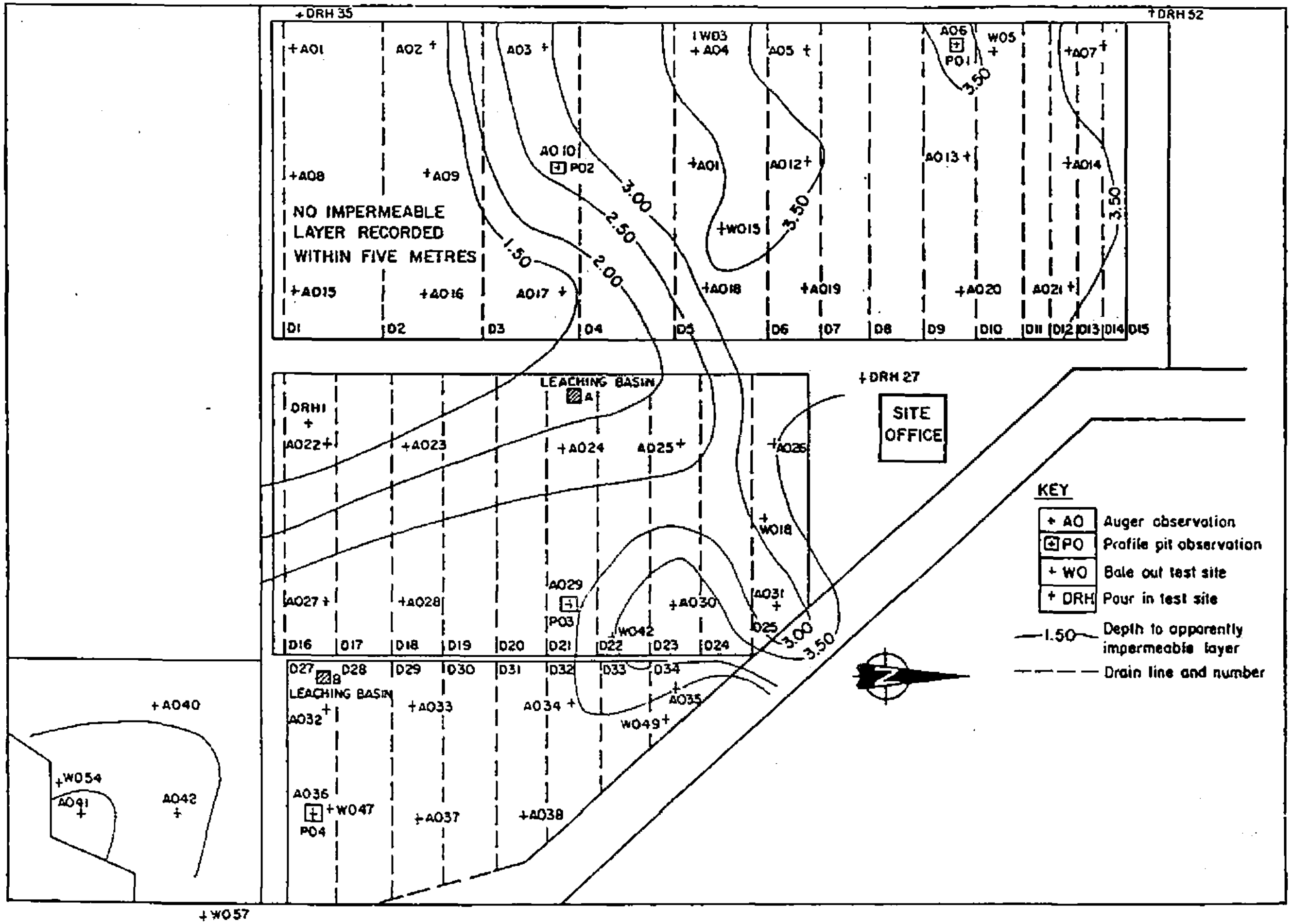

Figure 9. Soil observations and depth to impermeable layer

CONCLUSION

The pilot drainage scheme was evaluated using discharge and piezometer data recorded from 1986 to 1990. Performance of different drain spacings, combinations of drainage materials and efficiency of different envelope materials were also investigated. The Desalinization processes in the scheme in successive cropping seasons were evaluated from soil samples collected after each crop harvest. Based on these results, the following conclusions and recommendations were given:

- The sub–surface drainage system using perforated corrugated plastic pipes are effective in reclamation of saline and saline-sodic soils;

- Based on measurement of discharge and hydraulic head values of hydraulic conductivity computed using the Hooghoudt equations were in the range 2–5 m day^{-1}. This allows for a drain spacing of 50–60 meters at a drain depth of 2.0 meter;

- For a medium–textured alluvial soil as found throughout the Middle Awash Valley, the following drainage criteria can be used;
    - Minimum depth to water table 1.3 m with a corresponding hydraulic head of 0.7 m Mid way between the drains;
    - Hydraulic conductivity = 2.0 m day^{-1};
    - drain discharge = 2 mm day^{-1};

- The tests on the hydraulic properties of the pipes and filter materials indicated that the best combinations were perforated corrugated plastic pipe (PVC) with 60 and 80 mm nominal diameter, surrounded with an envelope of red–ash and with a minimum pipe grading of 0.1%.

- Results from soil monitoring indicated that the salinity levels can be reduced quickly if an acceptable narrow drain spacing, about 40 m, is used and a normal percolation losses associated with the surface irrigation supply.In the Middle Awash, where evapotranspiration is greatly exceeding precipitation, it is advisable to keep the land under continuous cropping (wet) to avoid movement of salt to the surface from shallow ground water in course of alternate wetting and drying.

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Appendix 1. Soluble cations and anions of soils, field 4c/6, 75 meters drain spacing

Sampling site	Soil depth (cm)	1989 Cations (me l⁻¹) Na^+	K^+	Ca^{++}	Mg^{++}	1989 Anions (me l⁻¹) HCO_3^-	Cl^-	1990 Cations (me l⁻¹) Na^+	K^+	Ca^{++}	Mg^{++}	1990 Anions (me l⁻¹) HCO_3^-	Cl^-
AO1	0-30	-	-	-	-	-	-	150.1	0.2	11.3	8.1	3.5	120.0
	30-60	-	-	-	-	-	-	37.3	0.6	29.8	1.6	3.3	29.8
	60-90	-	-	-	-	-	-	71.5	0.1	29.7	2.3	3.4	49.1
	90-120	-	-	-	-	-	-	2.7	0.1	3.7	3.7	2.8	15.4
AO2	0-30	26.9	1.9	35.3	8.8	2.9	38.0	13.6	0.9	29.0	7.0	3.0	3.7
	30-60	26.5	1.5	24.5	6.2	2.2	21.9	9.6	0.5	27.5	6.3	3.2	5.4
	60-90	35.6	1.6	24.0	10.0	2.0	27.5	19.5	0.2	12.8	4.7	2.3	4.8
	90-120	49.0	1.5	16.7	14.6	2.1	32.8	18.6	0.1	9.0	5.0	3.0	8.0
AO3	0-30	13.7	1.1	9.5	2.4	2.6	2.9	6.4	0.5	5.2	3.1	4.1	10.3
	30-60	12.2	2.2	24.4	6.9	1.7	2.7	7.0	0.3	3.4	0.7	5.5	11.0
	60-90	7.1	2.8	23.4	6.3	1.9	5.8	7.3	0.2	2.3	1.2	3.5	10.6
	90-120	7.3	2.4	21.4	4.7	2.1	4.2	6.8	0.3	2.0	2.0	3.0	8.0
AO4	0-30	-	-	-	-	-	-	79.7	0.5	161.6	28.8	2.4	216.8
	30-60	-	-	-	-	-	-	56.0	0.1	64.0	56.6	1.6	152.0
	60-90	-	-	-	-	-	-	2.0	0.0	12.4	1.7	2.6	7.1
	90-120	-	-	-	-	-	-	6.8	0.5	66.4	20.0	1.6	94.4
AO8	0-30	-	-	-	-	-	-	103.5	0.7	26.7	2.6	3.4	5.5
	30-60	-	-	-	-	-	-	47.6	0.9	30.0	2.7	3.6	53.6
	60-90	-	-	-	-	-	-	108.6	0.2	25.8	nil	1.6	41.8
	90-120	-	-	-	-	-	-	19.5	0.6	33.0	1.7	1.7	24.3
AO9	0-30	143.5	1.7	100.0	31.6	1.8	252.8	144.6	4.4	140.0	9.5	2.6	251.5
	30-60	116.0	0.8	46.6	25.5	1.5	125.0	73.6	3.1	100.5	26.6	2.8	163.1
	60-90	97.1	0.3	27.5	13.7	1.8	75.1	84.5	2.4	62.1	26.6	2.5	146.6
	90-120	113.3	0.8	40.6	21.6	2.2	137.5	116.3	2.1	74.4	27.7	2.2	163.3
AO10	0-30	25.5	1.3	26.2	9.5	1.8	254.8	15.8	5.2	196.8	63.0	2.4	339.3
	30-60	23.3	1.8	31.3	10.4	1.5	125.0	107.6	2.0	71.0	15.4	2.3	147.9
	60-90	31.1	1.0	28.0	6.0	1.8	75.1	143.5	1.4	53.5	13.9	2.1	156.2
	90-120	40.3	0.7	26.0	6.0	2.2	137.5	157.3	1.4	53.4	30.7	3.0	137.4
AO11	0-30	105.0	5.3	93.7	43.7	1.5	189.8	23.9	1.1	32.0	50.8	2.0	21.6
	30-60	84.0	6.7	56.0	38.0	1.2	137.5	13.1	0.4	32.0	70.2	2.4	16.8
	60-90	86.5	4.3	60.5	32.5	1.7	150.6	7.4	0.5	15.2	5.6	2.8	14.4
	90-120	103.3	1.3	47.1	20.6	2.1	15.7	5.7	0.7	15.6	1.7	3.0	19.1
AO15	0-30	-	-	-	-	-	-	4.5	0.9	6.1	nil	4.1	5.5
	30-60	-	-	-	-	-	-	4.8	0.4	8.1	nil	4.5	6.1
	60-90	-	-	-	-	-	-	25.2	1.4	30.4	1.0	2.0	22.3
	90-120	-	-	-	-	-	-	43.1	1.3	28.0	2.8	1.6	37.4
AO16	0-30	141.3	1.8	135.0	60.0	1.7	288.1	19.9	2.1	41.7	0.6	2.6	51.3
	30-60	116.5	0.8	96.2	30.9	1.6	202.9	16.8	1.5	27.7	6.8	4.4	41.1
	60-90	96.9	0.4	52.5	25.0	1.5	121.8	24.4	1.2	43.5	2.9	1.9	69.3
	90-120	103.3	0.4	56.0	20.0	1.4	137.5	41.9	0.6	30.7	8.4	2.3	30.7
AO17	0-30	12.6	0.4	15.2	30.0	2.7	3.8	5.1	0.6	8.1	2.3	3.5	12.7
	30-60	19.4	0.3	30.0	7.5	1.5	4.5	21.6	0.5	59.5	2.1	2.1	56.5
	60-90	21.1	0.3	29.4	Trace	1.7	5.8	8.0	0.6	27.7	5.5	2.2	13.3
	90-120	26.1	0.3	23.9	2.2	1.5	11.0	48.7	0.7	59.5	10.7	1.9	90.7
AO18	0-30	72.5	4.2	100.0	25.0	1.8	15.7	2.9	1.1	4.8	3.2	3.6	10.4
	30-60	81.3	4.4	91.8	25.0	1.0	161.9	2.6	0.6	3.2	1.6	3.2	7.2
	60-90	122.2	1.4	64.4	27.2	1.9	128.5	1.1	0.2	2.6	1.7	3.5	6.9
	90-120	70.5	0.7	71.8	30.7	1.8	162.2	2.4	0.1	4.0	0.8	3.2	8.0

Appendix 2. Soluble cations and anions of soils, field 4c/7, 20 and 40 meters drain spacings.

Sampling site	Soil depth (cm)	1989 Soluble cations (me l-1)				1989 Soluble anions (me l-1)		1990 Soluble cations (me l-1)				1990 Soluble anions (me l-1)	
		Na+	K+	Ca++	Mg++	HCO3-	Cl-	Na+	K+	Ca++	Mg++	HCO3-	Cl-
AO5	0-30	5.5	0.8	10.4	nil	1.6	0.9	8.7	0.6	7.2	2.4	2.4	0.6
	30-60	4.6	0.4	6.1	nil	1.6	0.4	5.7	0.2	4.0	1.2	2.4	8.0
	60-90	3.8	0.1	5.8	nil	1.9	0.4	8.1	0.1	3.4	6.6	1.3	25.3
	90-120	5.7	0.2	12.3	nil	2.0	0.5	4.8	0.1	2.4	1.6	1.6	7.2
AO6	0-30	-	-	-	-	-	-	2.9	0.6	3.6	2.4	2.8	6.6
	30-60	-	-	-	-	-	-	3.8	0.2	3.0	2.0	1.0	6.1
	60-90	-	-	-	-	-	-	3.7	0.1	2.7	0.9	3.6	7.3
	90-120	-	-	-	-	-	-	3.2	0.1	2.8	1.6	3.0	8.1
AO7	0-30	24.0	1.8	1.7	nil	2.6	4.0	3.2	0.5	3.0	0.7	4.8	49.7
	30-60	24.5	0.5	4.8	nil	1.6	3.6	2.0	0.2	1.3	1.3	4.0	7.0
	60-90	32.4	0.2	19.3	nil	1.6	18.5	3.2	0.2	2.5	0.4	2.7	6.7
	90-120	32.4	0.1	22.9	nil	2.0	34.6	2.8	0.1	1.7	0.4	2.7	6.7
AO12	0-30	10.5	2.2	23.0	7.7	3.1	3.6	3.5	1.3	5.2	1.2	3.2	5.5
	30-60	9.9	2.8	30.0	5.0	1.8	5.6	3.5	0.6	4.8	1.6	3.2	9.6
	60-90	14.4	2.5	30.0	10.0	1.7	10.6	10.9	0.6	25.3	4.0	2.8	38.6
	90-120	20.4	1.0	30.0	6.6	1.3	17.5	24.5	0.6	58.0	6.3	1.3	85.3
AO13	0-30	-	-	-	-	-	-	3.9	0.7	4.7	2.2	2.8	7.9
	30-60	-	-	-	-	-	-	12.8	0.6	17.7	1.2	2.9	11.7
	60-90	-	-	-	-	-	-	19.5	0.5	21.5	1.2	1.6	17.7
	90-120	-	-	-	-	-	-	26.5	0.3	20.0	4.0	3.2	26.6
AO14	0-30	16.6	0.6	32.3	6.6	1.2	31.9	1.9	0.4	2.3	0.6	3.1	7.5
	30-60	30.5	0.5	46.5	13.5	1.3	57.7	3.0	0.3	6.0	1.0	2.4	3.2
	60-90	55.1	0.3	56.4	16.1	1.2	92.9	3.6	0.6	3.3	0.6	4.2	2.6
	90-120	63.7	0.3	61.5	10.3	1.0	106.1	3.8	0.1	2.5	nil	3.0	6.0
AO19	0-30	17.5	2.6	32.5	7.5	3.0	39.4	2.3	0.6	5.6	2.4	4.0	6.6
	30-60	37.3	1.9	40.0	13.3	1.3	93.9	1.9	0.5	5.6	1.6	3.2	6.0
	60-90	42.5	1.8	44.4	11.1	1.9	63.2	4.7	0.2	1.6	0.6	1.6	2.6
	90-120	47.7	0.7	40.9	6.6	1.8	56.1	1.7	0.2	1.6	1.2	1.5	4.8
AO20	0-30	-	-	-	-	-	-	3.3	0.5	3.9	1.1	1.8	4.5
	30-60	-	-	-	-	-	-	5.9	0.8	12.0	1.0	1.6	7.2
	60-90	-	-	-	-	-	-	14.4	0.6	14.0	4.0	2.4	16.0
	90-120	-	-	-	-	-	-	18.7	0.5	15.5	3.5	1.9	19.0
AO21	0-30	5.1	0.6	11.9	2.4	1.9	5.6	5.4	0.6	6.2	1.7	4.4	11.0
	30-60	10.4	0.7	26.1	6.5	1.3	10.1	6.4	0.3	16.3	1.2	2.4	6.7
	60-90	15.3	0.3	31.1	6.6	1.2	16.9	7.2	0.1	11.9	1.6	2.0	11.9
	90-120	12.0	0.1	26.1	6.7	0.8	16.1	6.5	0.9	11.2	20.1	2.0	13.4

Appendix 3. Soluble cations and anions of soils, field 4c/10A, drainage material tests

Samping site	Soil depth (cm)	1989 Cations (me l⁻¹) Na+	K+	Ca++	Mg++	1989 Anions (me l⁻¹) HCO3-	Cl-	1990 Cations (me l⁻¹) Na+	K+	Ca++	Mg++	1990 Anions (me l⁻¹) HCO3-	Cl-
AO22	0-30	-	-	-	-	-	-	1.7	0.2	1.6	0.5	2.0	6.0
	30-60	-	-	-	-	-	-	2.2	0.1	1.9	0.5	2.0	5.0
	60-90	-	-	-	-	-	-	1.2	0.2	1.2	0.5	3.0	7.0
	90-120	-	-	-	-	-	-	4.3	0.1	3.0	1.5	2.4	9.6
AO23	0-30	4.2	0.3	4.5	2.2	1.6	1.4	4.2	0.3	4.6	2.1	2.5	11.1
	30-60	3.5	0.3	23.2	0.9	1.4	0.3	2.5	0.1	1.6	1.5	1.6	6.5
	60-90	2.0	0.1	6.1	3.1	1.3	0.3	2.0	0.1	1.3	1.9	2.1	5.3
	90-120	0.9	0.1	5.6	nil	1.7	0.4	2.4	0.1	2.3	1.7	1.6	6.5
AO24	0-30	-	-	-	-	-	-	1.9	0.9	3.4	0.6	4.2	15.7
	30-60	-	-	-	-	-	-	1.7	0.4	2.4	nil	4.5	23.7
	60-90	-	-	-	-	-	-	1.5	0.2	2.6	nil	2.5	6.7
	90-120	-	-	-	-	-	-	1.4	0.1	2.5	0.6	3.6	6.6
AO25	0-30	1.6	0.4	4.4	nil	2.0	1.1	2.2	0.6	3.9	nil	4.5	9.1
	30-60	1.2	0.2	2.3	nil	2.1	0.3	2.5	0.2	3.9	nil	3.5	7.1
	60-90	0.6	0.2	3.0	nil	2.2	0.2	2.2	Trace	4.1	nil	2.2	6.5
	90-120	1.9	0.1	4.0	nil	1.6	1.2	3.0	Trace	3.6	0.6	2.1	7.2
AO26	0-30	4.7	0.5	7.6	nil	1.9	6.3	4.3	1.3	6.7	3.0	3.9	14.1
	30-60	3.7	0.3	6.0	4.0	3.4	4.2	2.7	0.3	2.9	nil	3.7	13.0
	60-90	1.7	0.2	16.2	4.3	3.2	0.9	7.7	0.2	2.6	2.6	3.3	12.2
	90-120	1.2	0.1	6.0	4.0	2.6	2.2	2.7	0.2	2.9	1.5	2.3	10.6
AO27	0-30	-	-	-	-	-	-	2.9	0.2	3.1	0.5	2.0	3.0
	30-60	-	-	-	-	-	-	6.2	0.3	2.3	1.5	2.4	4.8
	60-90	-	-	-	-	-	-	1.5	0.2	1.6	0.6	3.0	6.0
	90-120	-	-	-	-	-	-	3.3	0.1	1.6	0.6	1.0	6.0
AO28	0-30	3.7	0.2	10.0	5.0	1.6	1.4	1.6	0.3	2.3	1.7	3.7	6.6
	30-60	4.2	0.1	6.9	1.4	1.4	0.3	1.4	0.2	2.5	1.6	1.3	4.0
	60-90	2.2	0.1	5.5	2.6	1.3	0.2	1.3	0.1	2.5	1.7	2.0	6.0
	90-120	3.9	0.1	5.4	nil	1.6	0.4	1.4	0.2	2.1	2.6	2.2	6.6
AO29	0-30	-	-	-	-	-	-	2.1	0.2	2.5	nil	5.0	11.0
	30-60	-	-	-	-	-	-	2.2	0.1	1.9	0.6	5.1	6.2
	60-90	-	-	-	-	-	-	1.6	0.1	2.4	0.6	5.9	12.2
	90-120	-	-	-	-	-	-	3.9	0.1	2.7	nil	1.7	10.6
AO30	0-30	3.6	0.2	2.9	1.4	2.3	1.1	2.5	0.4	5.0	1.2	4.0	10.1
	30-60	6.1	0.1	2.7	1.4	1.9	2.6	5.3	0.6	22.4	2.6	2.1	11.6
	60-90	9.5	0.1	4.5	2.3	1.6	5.1	6.5	0.6	30.5	4.3	0.9	15.3
	90-120	4.6	0.1	2.3	nil	1.6	2.0	3.6	0.4	27.9	2.9	0.9	12.0
AO31	0-30	1.7	0.3	1.6	nil	3.4	4.2	4.6	0.9	5.4	0.9	2.5	11.6
	30-60	5.3	0.2	3.9	nil	1.6	0.6	3.6	0.5	5.3	4.2	2.5	9.4
	60-90	2.6	0.2	2.9	nil	1.7	0.6	3.2	0.3	5.4	5.4	2.6	6.7
	90-120	3.7	0.1	3.3	nil	1.4	0.2	60.7	0.6	51.6	17.6	3.5	115.5

- not analyzed

Appendix 4. Meteorological data (1969-1990) of Melka Werer Research Center

Month	Mean daily Temp. °C	Humidity (%)	Wind speed (km day $^{-1}$)	Sun shine (hrs.)	Evaporation (mm)	Rainfall (mm)	ETo-Penman (mm day $^{-1}$)
January	24.3	52	121	8.7	7.2	15.4	4.3
February	25.3	52	128	8.5	7.7	54.9	4.7
March	27.1	51	129	8.3	8.4	68.7	5.2
April	28.1	50	123	8.3	8.6	63.4	5.4
May	29.6	43	142	9.0	9.8	28.9	5.9
June	31.3	37	212	8.5	11.2	22.6	6.9
July	28.8	49	217	7.0	9.1	110.1	5.9
August	27.4	57	175	7.4	7.6	118.0	5.3
September	27.9	52	144	7.9	8.3	46.6	5.4
October	26.5	46	124	9.1	8.6	21.4	5.1
November	24.9	47	121	9.7	8.1	11.1	4.7
December	23.4	50	114	9.2	7.1	3.0	4.2
Year	27.1	49	146	8.5	8.5	564.0	1922

Reference Evapotranspiration (ETo) according Penman-Monteith