In which

C = Coefficient of discharge

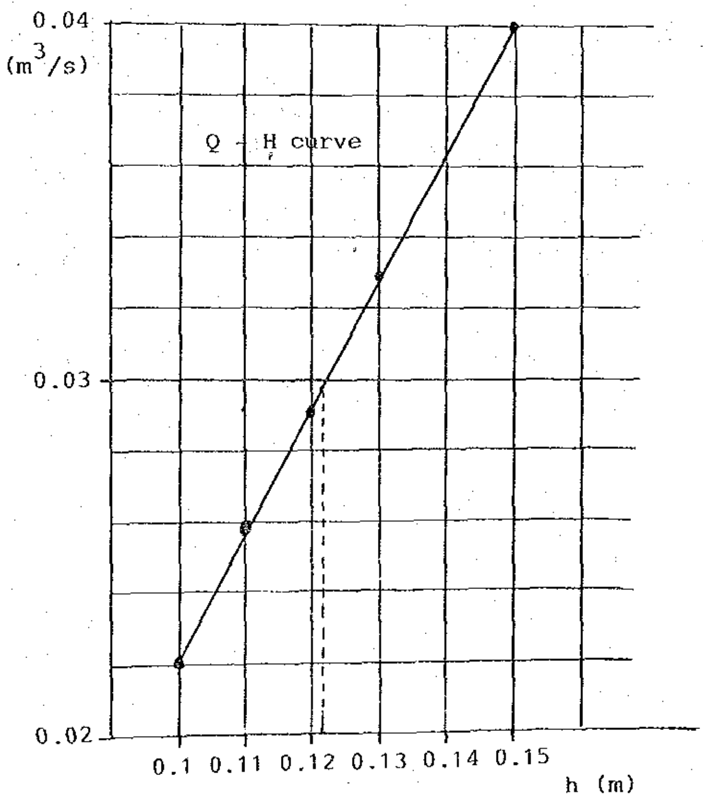
b = Width of weir (= 0.40 m)

h = Over flow depth

(Table-2)

h	Q
0.10	0.022
0.11	0.026
0.12	0.029
0.13	0.033
0.15	0.040

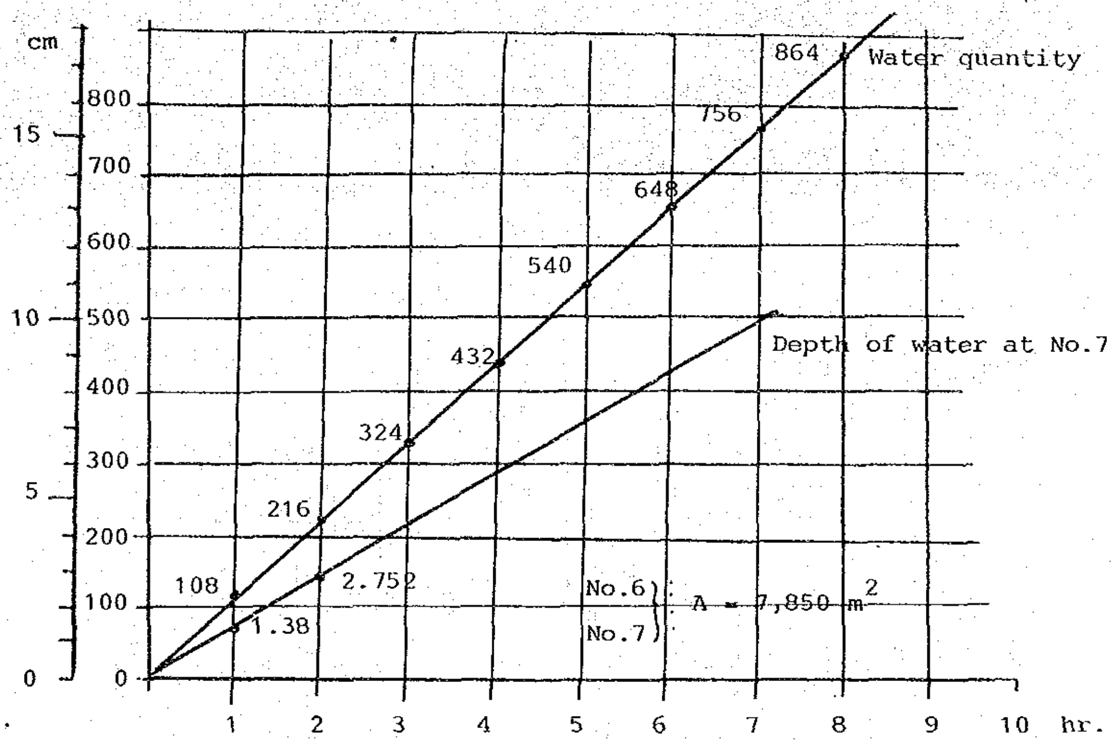
(fig-5)



- Water requirement according to the design criteria

1) Water supply capacity by hour

(fig-6)



In order to record the water range and the depth of flooding water by the hour, 21 stakes were driven in at the plot No.6 and No.7 respectively.

v) <u>Checking the first stage consumptive use of water</u> (Pre-irrigation for plowing)

:- Preparatory water is estimated at 30 mm in the detailed design

:- Time to be supplied to an experimental plot can be calculated as shown below.

$$7,850 \times \frac{30}{1,000} = 235.5 \ m^3$$

$$235.5 - 30 \ l/s = 2 \ 10' \ 50''$$

in which

acreage of a plot = $7,850 \ m^2$

preparatory water in meter = $\frac{30}{1,000}$

Test discharge from the farm inlet = 30 l/m

:- Investigation Result

i) Experimental plot No.1 (plot No.6)

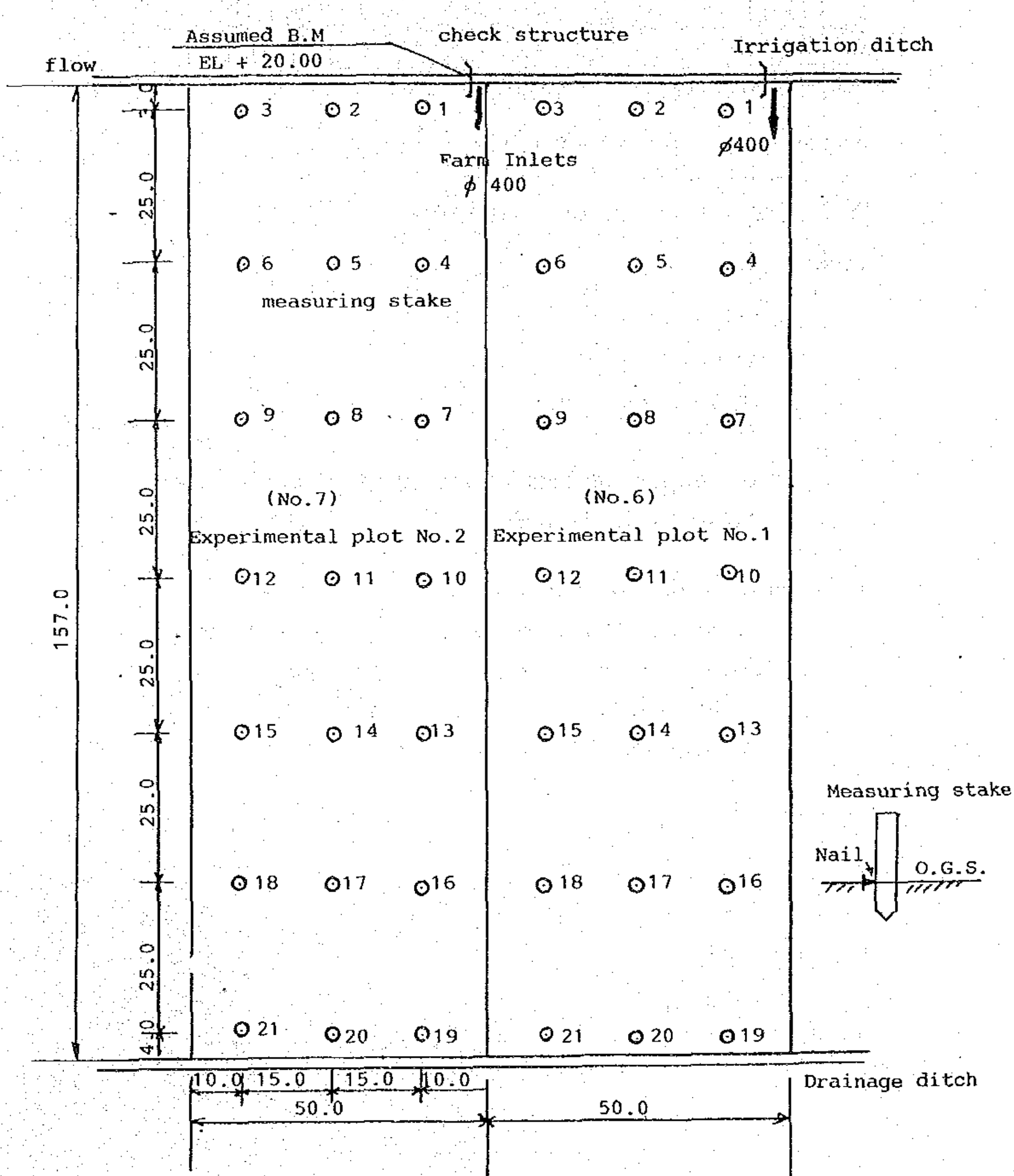
- 30 mm of scheduled preporatory water could cover only 27 % of the acreage of the plot. ($2,125 \ m^2/7,850 \times 100 = 27$ %)
- It can be concluded that 30 mm of preparatory water is not enough.

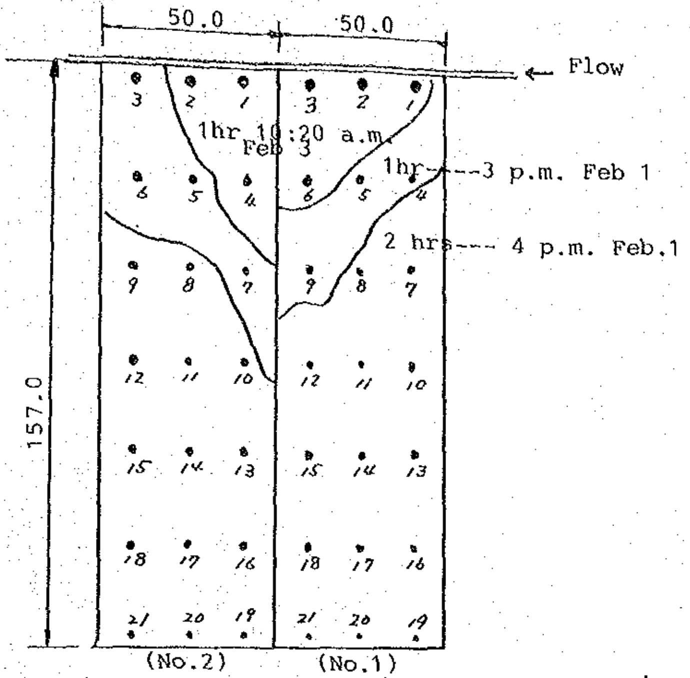
ii) Experimental plot No.2 (No.7)

- 30 mm of scheduled preparatory water could cover only 34 % of the acreage of the plot. ($2,680 \ m^2/7,850 \ m^2 \times 100 = 34$ %)
- Conclusion : not enough.

Water was supplied from a farm-inlet (∅ 35 cm)

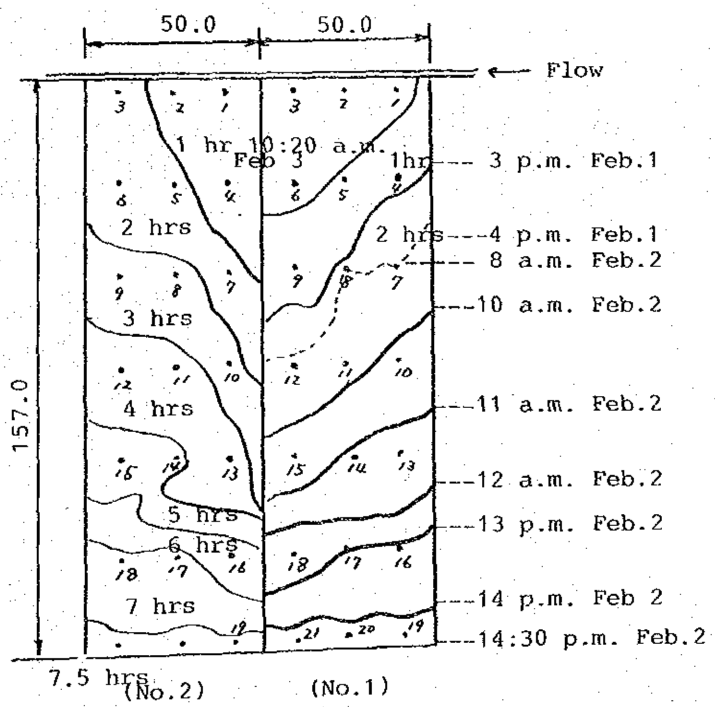
vi) Preparations at the field





Experimental plot

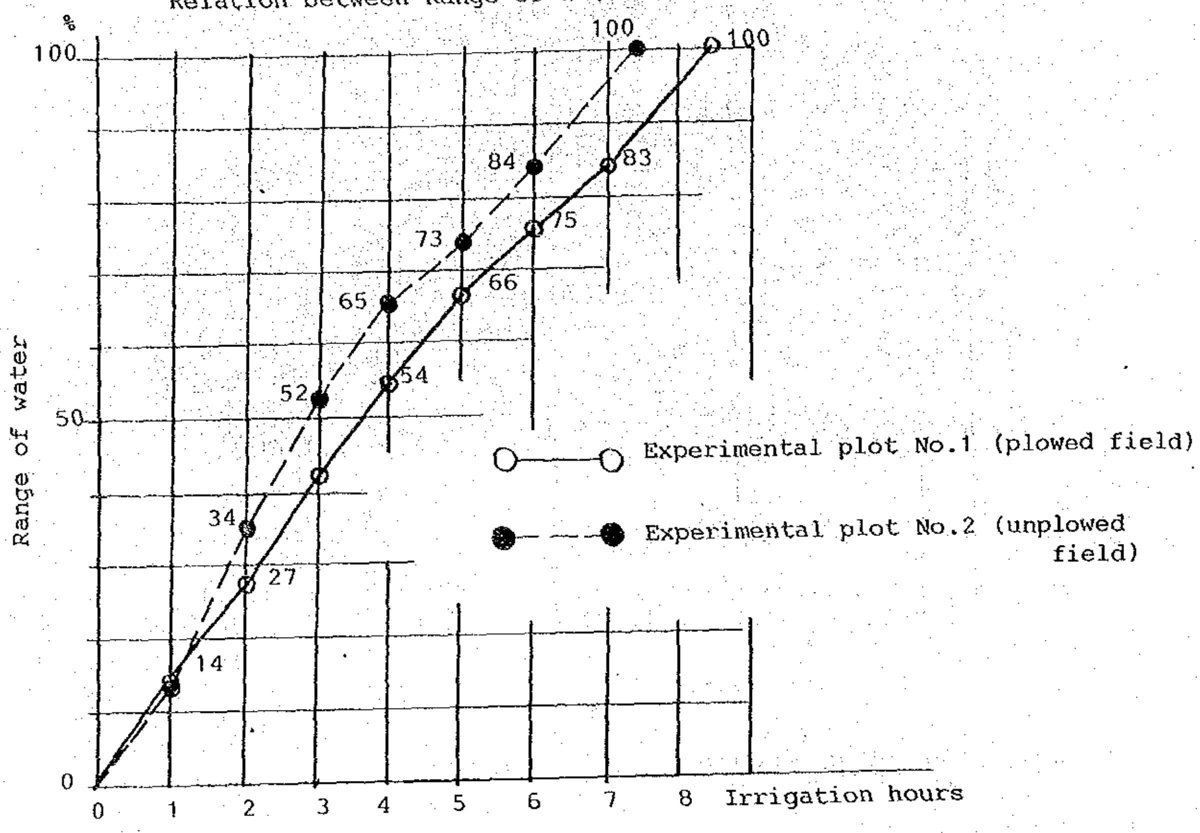
vi) Range of irrigation water by the hour



Experimental plot

Note : Regarding the investigation at the experimental plot No.1 Owing to the starting time, the supply of water was stopped at 4 p.m Feb.1 and begun at 8 a.m the next day After starting, it took about one hour for the water to reach the saturation line.

Relation between Range of Water and Time



As I mentioned before and as a picture shows, experimental plot No.1 had already been plowed so that it took one hour longer than plot No.2.

vii) Hours and quantity of irrigation water required to cover a plot completely

Plot 1	Hours	:	8.5
	Quantity	:	918 m^3....116.9 mm
	(8.5 hr x 30 l/sec)		
Plot 2	Hours	:	7.5
	Quantity	:	810 m^3....103.2 mm

viii) Hours and quantity of irrigation water sufficient for puddling

Plot 1	Hours	:	10.0
	Quantity	:	1,080 m^3....137.6 mm
Plot 2	Hours	:	10.0
	Quantity	:	1,080 m^3....137.6 mm

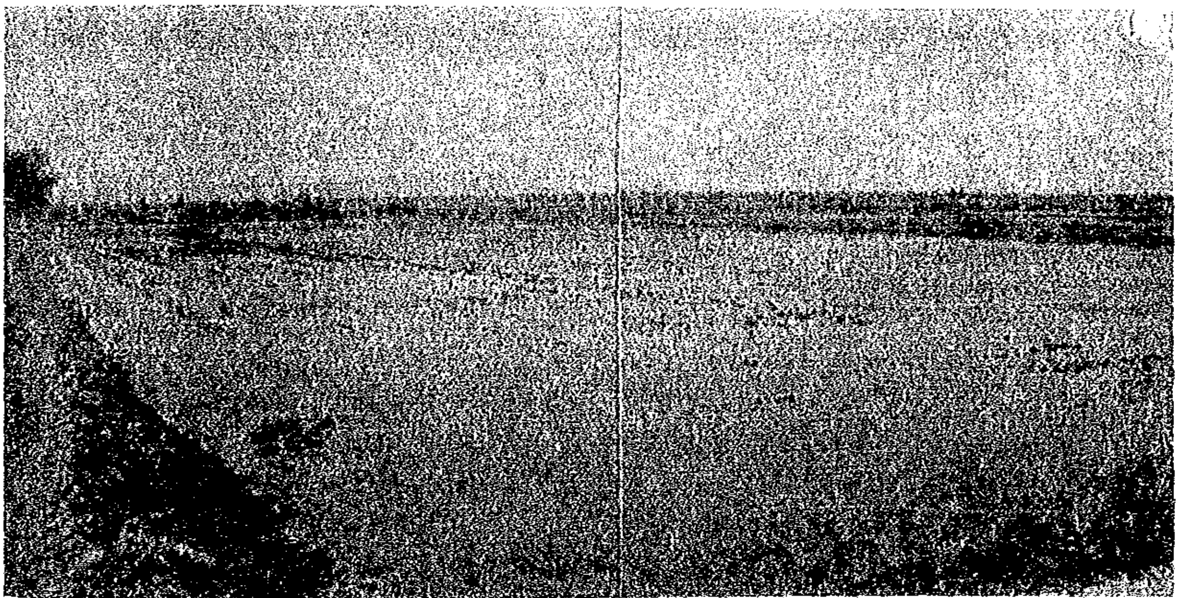
These values seem to be the same as plot 6 but plot No.2 has not been plowed so that some depth of surface needs more water for puddling.

Sufficient water for puddling

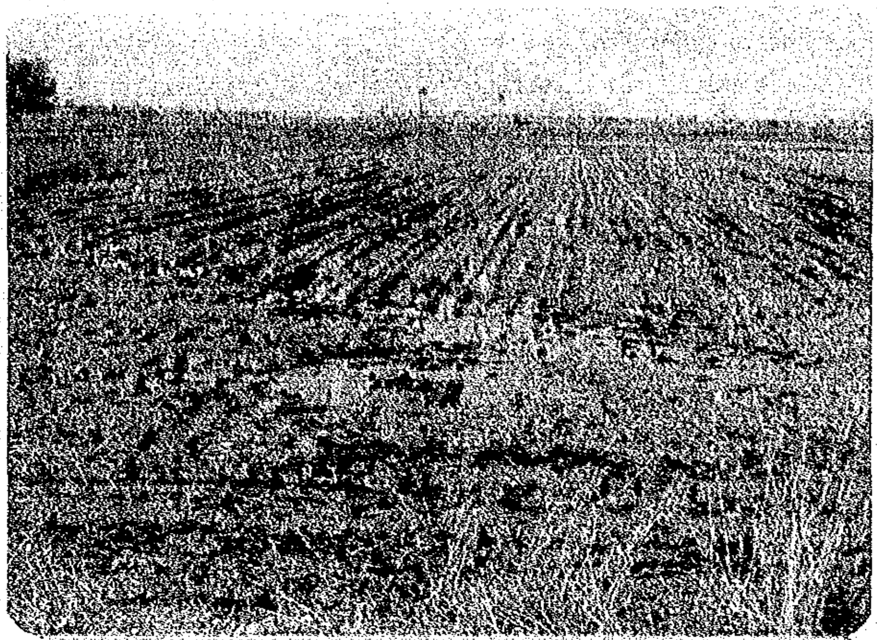
Hours : 12.0

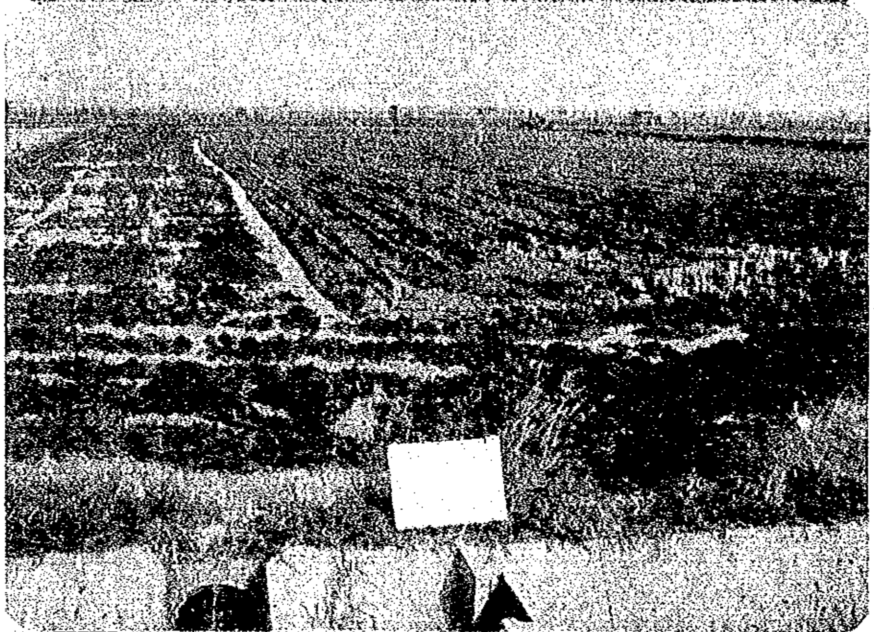
Quantity : 1,296 m^3 .... 165.1 mm

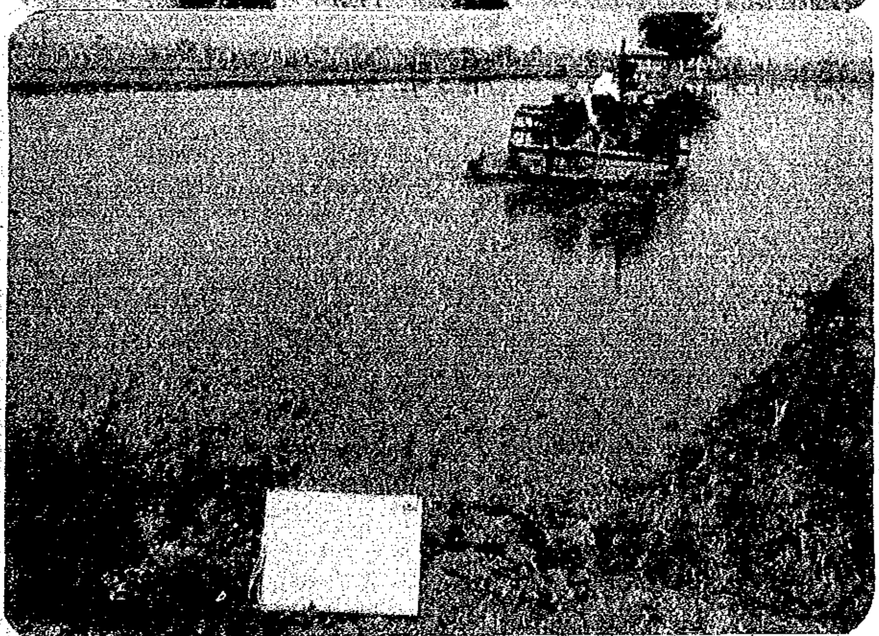
Plot 1



Plot 2







ix) The condition change of the irrigated water at the plot

- Supplied water analysis -

:- Irrigation test

Plot 1 : 1st started 14:00 Feb.1,1983

stopped 16:00 -ditto-

2nd started 8:00 Feb.2,1983

ended 14:30 -ditto-

Stake No.	Spot-height	7:00-8:00 a.m Feb.3		12:00-13:00 Feb.7	
		Flooding depth (m)	EL.of water surface	Flooding depth(m)	EL of water surface
1	19.484	0.050	19.534	0.025	19.509
2	19.493	0.041	19.534	0.015	19.508
3	19.529	0.005	19.534	0.018	19.547
4	19.446	0.101	19.547	0.077	19.523
5	19.475	0.061	19.536	0.037	19.512
6	19.480	0.055	19.535	0.032	19.512
7	19.502	0.032	19.534	0.008	19.510
8	19.465	0.073	19.538	0.050	19.515
9	19.445	0.095	19.540	0.071	19.516
10	19.470	0.063	19.533	0.038	19.508
11	19.460	0.075	19.535	0.054	19.514
12	19.467	0.074	19.541	0.053	19.520
13	19.480	0.051	19.531	0.027	19.507
14	19.455	0.085	19.540	0.057	19.512
15	19.405	0.127	19.532	0.104	19.509
Ave.	19.470	0.066	19.536	0.044	19.514

Stakes No.16-21 : Leveling had not been done yet.

Covering area by the stake No.1-15 assumed as follows

50 m (width) x 115.5 m (length) = 5,775 m^2

Total acreage of plot No.1 = 7,850 m^2

Quantity of flooding water:

1 day after irrigation 0.066 x 5,755 = 381 m^3

Total quantity of water supplied to plot No.1

10 hrs x 30 l/sec = 1,083 m^3

Allocated quantity of water supplied to the covering area by stake Nos.1-15.

$1,080 \times 5,775\ m^2 / 7,850\ m^2 = 795\ m^3$

Saturated water capacity after about 8 hours

$$\frac{795 - 381}{795} \times 100 \doteqdot 52\ \%$$

:- 4 days after irrigation

Quantity of flooding water :

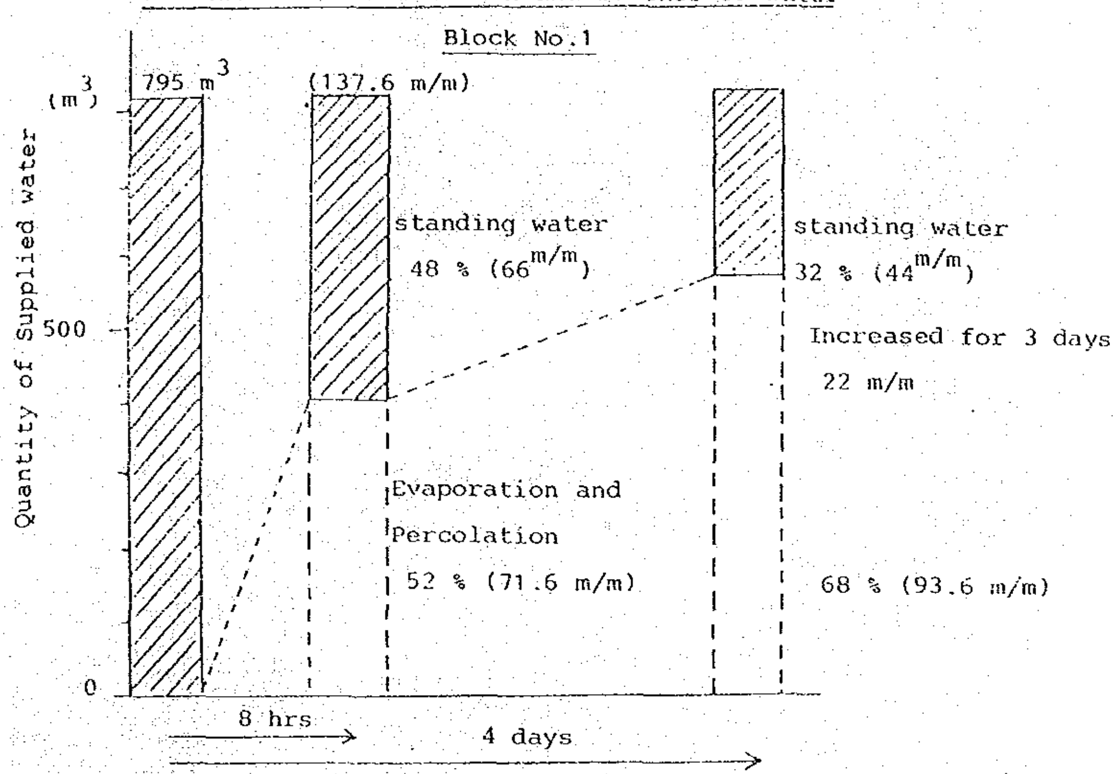
$0.044 \times 5,775 = 254\ m^3$

Saturated water capacity for about 4 days

$$\frac{795 - 254}{795} \times 100 = 60\ \%$$

Relation between Duration and Demenor of water

Block No.1



Plot 2 : started 9:20 Feb.3, 1983
ended 16:50 - ditto -

Stake No.	Spot-height (m)	12:00 - 13:00 p.m. Feb.8	
		Flooding depth (m)	EL of water surface
1	19.534	0.003	19.538
2	19.541	0.009	19.550
3	19.510	0.029	19.540
4	19.500	0.048	19.548
5	19.505	0.039	19.544
6	19.505	0.033	19.538
7	19.527	0.020	19.547
8	19.525	0.014	19.539
9	19.535	0.008	19.543
10	19.505	0.036	19.541
11	19.517	0.022	19.539
12	19.472	0.012	19.484
13	19.515	0.019	19.534
14	19.482	0.054	19.536
15	19.500	0.040	19.540
16	19.484	0.046	19.530
17	19.464	0.070	19.534
18	19.450	0.082	19.582
19	19.440	0.084	19.528
20	19.442	0.087	19.529
21	19.457	0.069	19.526
Ave.	19.496	0.041	19.537

Total acreage of plot 2 = 7.850

Quantity of flooding water:

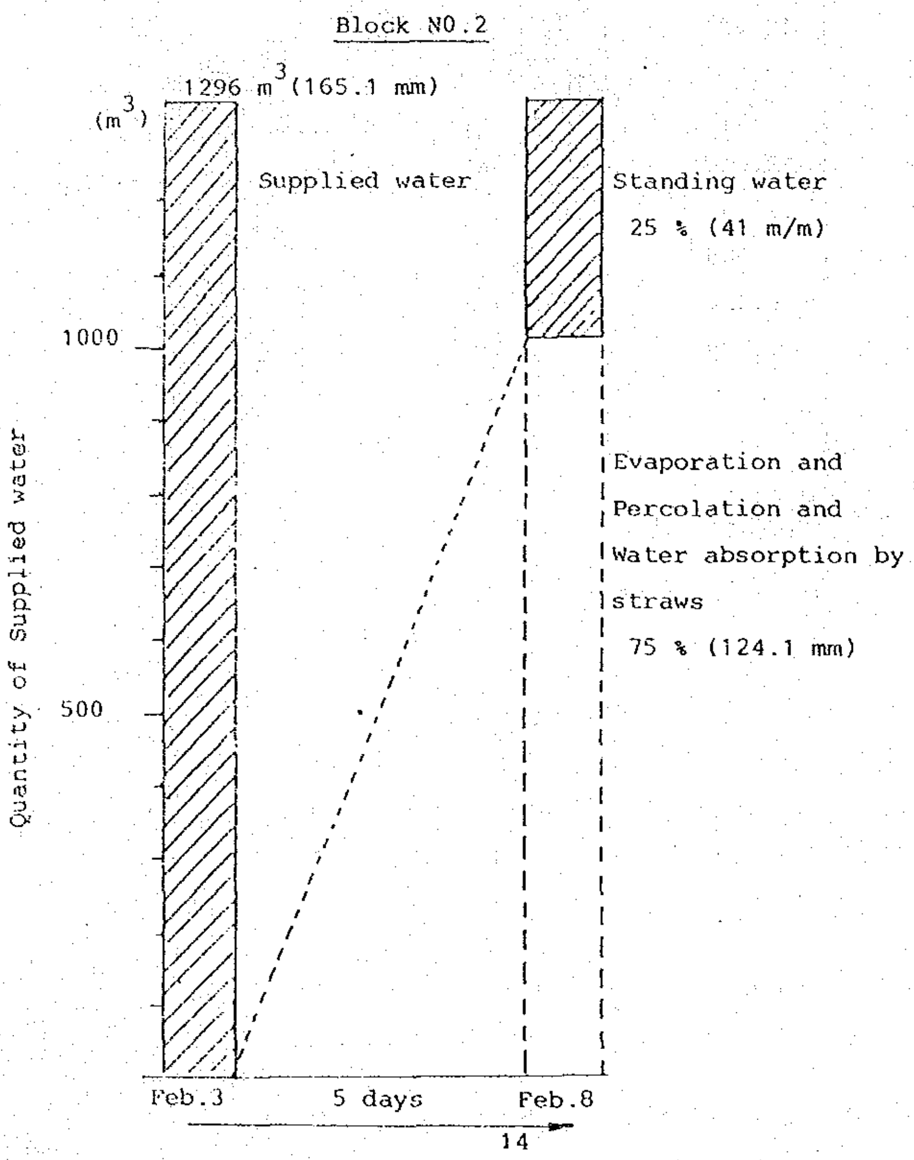
$0.041 \times 7.850 = 322\ m^3$

Total quantity of water supplied to plot No.2

12 hrs. x 30 l/sec = 1.296 m^3

Saturated water capacity after about 5 days

$$\frac{1,296 - 322}{1,296} \times 100 = 75\ \%$$



\# Refer to the climatological data for the period 1951 - 1970 in Kanchanaburi

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station KANCHANABURI
Index station 48 450
Latitude 14 01'N.
Longitude 99 32'E.

Elevation of station above MSL. 28.00 meters
Height of barometer above MSL. 29.39 meters
Height of thermometer above ground 1.20 meters
Height of wind vane above ground 11.40 meters
Height of raingauge 0.64 meters

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Pressure(+100or900 mbs)													
Mean	13.24	11.65	10.04	08.95	07.49	07.42	07.19	07.13	07.81	10.54	12.49	13.36	09.78
Ext. Max.	24.34	22.15	19.77	20.18	14.53	15.76	14.25	14.38	15.03	18.02	21.37	23.62	24.34
Ext. Min.	04.71	03.50	01.62	01.60	99.37	01.80	99.95	00.26	98.50	02.56	06.11	05.60	98.50
Mean daily range	5.29	5.63	5.91	5.76	4.97	4.06	3.93	3.98	4.53	4.64	4.68	4.83	4.85
Temperature(C.)													
Mean	24.9	27.6	30.0	31.2	30.0	29.0	28.5	28.4	28.0	27.0	25.8	24.3	27.9
Mean Max.	32.4	34.8	36.9	37.8	35.4	33.6	32.9	32.7	32.4	31.2	30.9	30.8	33.5
Mean Min.	17.5	20.4	22.8	24.7	24.9	24.5	24.0	24.0	23.7	22.9	20.8	17.9	22.3
Ext. Max.	37.2	40.0	41.7	43.5	41.6	38.4	37.8	37.5	37.6	37.3	37.5	35.3	43.5
Ext. Min.	5.5	12.8	11.0	17.2	21.9	22.0	20.8	21.5	20.8	18.9	12.0	9.0	5.5
Relative Humidity (%)													
Mean	61.8	60.1	56.3	58.7	70.0	72.1	73.1	73.9	77.0	79.5	74.5	68.5	68.8
Mean Max.	87.8	85.8	82.1	83.0	87.5	87.9	88.8	89.4	91.4	93.2	91.8	90.1	88.2
Mean Min.	41.8	40.2	36.1	39.0	53.1	57.8	58.6	58.9	61.8	65.3	58.9	49.9	51.8
Ext. Min.	11.0	16.0	14.0	17.0	24.0	32.0	34.0	35.0	36.0	43.0	32.0	21.0	11.0
Dew Point(C)													
Mean	17.3	19.1	19.9	21.7	23.5	23.1	23.0	22.9	23.2	23.2	21.1	18.2	21.4
Evaporation(mm)													
Mean—Piche	104.2	109.9	143.0	138.5	101.9	93.6	81.6	83.5	66.8	57.3	67.8	82.1	30.2
—Pan						No observation							
Cloudiness(0-8)													
Mean	3.3	3.5	3.6	4.4	5.8	6.6	6.8	6.9	6.7	5.8	4.5	3.6	5.1
Visibility (Km.)													
0700 L.S.T.	4.9	4.3	5.4	7.8	9.6	10.2	9.5	9.0	8.6	8.0	7.0	6.3	7.6
Mean	8.3	7.1	7.3	9.5	11.2	11.9	10.8	10.7	10.4	10.1	10.3	9.6	9.8
Wind (Knots)													
Prevailing wind	NE	SE	W	W	W	W	W	W	W	W	NE	NE	-
Mean Wind Speed	3.3	3.8	4.2	4.6	4.4	4.6	4.5	5.0	3.9	3.4	3.5	4.1	-
Max. Wind Speed	25ENE	25SE	33S	50SE	33E,W	33W	55SW	40NW	40W	30W	21NE	30N	-
Rainfall(mm)													
Mean	2.7	21.8	26.8	72.7	153.5	91.0	107.1	100.4	235.6	236.0	60.7	8.6	1116.9
Mean rainy days	1.0	2.1	3.4	6.2	14.0	13.1	15.9	16.9	18.7	15.3	5.0	1.6	113.2
Greatest in 24 hr.	16.4	82.0	45.8	72.1	95.4	70.8	64.7	73.9	104.5	162.8	117.6	45.6	162.8
Day/Year	10/65	14/70	7/65	30/58	4/63	28/58	23/57	28/54	21/70	12/70	3/69	21/66	12/70
Number of days with													
Haze	23.5	25.1	26.9	15.5	6.3	3.6	3.4	3.7	3.1	5.9	10.0	16.0	143.0
Fog	6.1	6.5	2.2	2.0	2.0	0.5	0.9	1.2	1.4	2.2	3.3	3.5	31.8
Hail	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.6
Thunderstorm	0.2	1.9	4.2	9.7	12.9	4.8	6.3	5.0	8.2	7.4	1.5	0.4	62.5
Squall	0.0	0.1	0.0	0.6	0.1	0.1	0.2	0.1	0.2	0.0	0.0	0.0	1.4

x) Softening of soil after irrigation

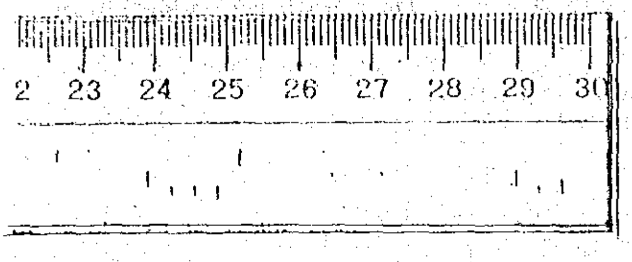
As has been consistently shown, this kind of soil becomes very soft after irrigation.

I considered that checking how deep the soil becomes soft was important for plowing and for machines.

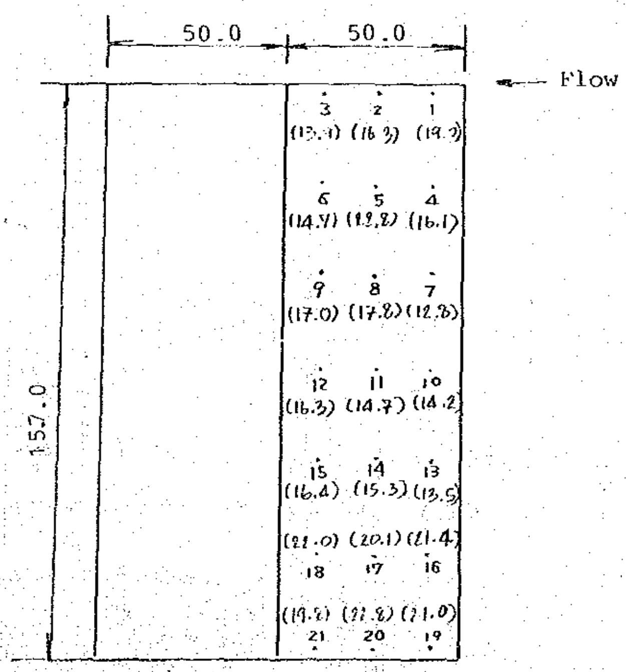
So I measured the depth where the hard layer was by using a plastic ruler, striking the ruler three or four times into the soil with my right hand.

The ruler which was used to sound the hard layer:

Thickness : 2 mm.

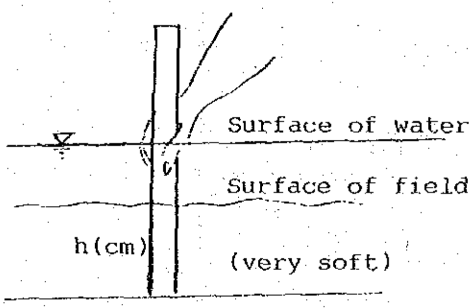


Survey date : Feb.3, 1983 8 hrs. after irrigation



(No.2) (No.1)

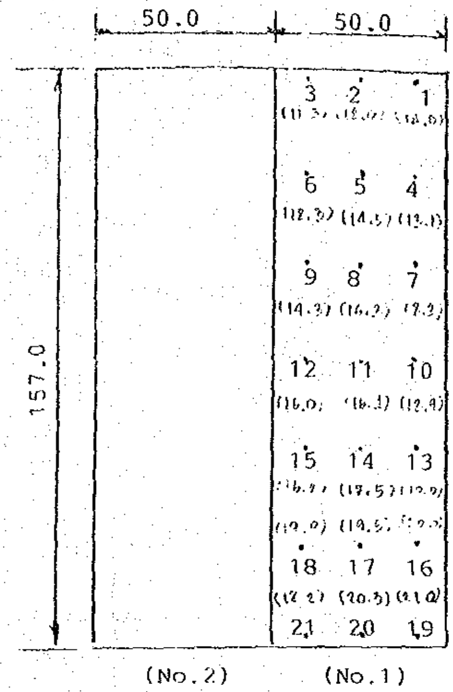
Experimental plot



"h" is shown in brackets

average depth : 17.5 cm.

Survey date : Feb.7 5 days after irrigation



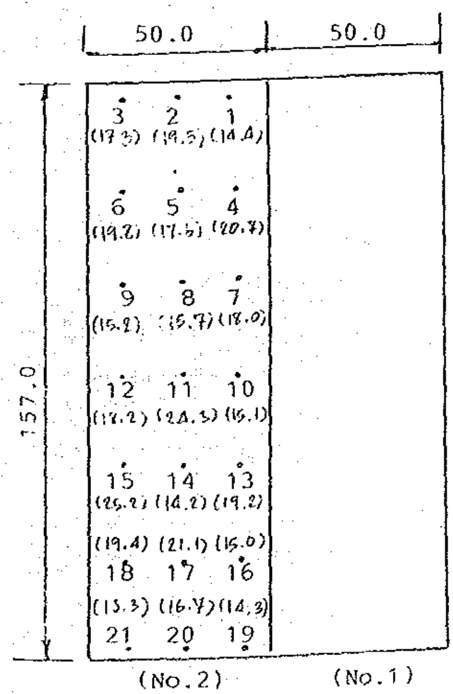
Experimental plot

Average depth : 13.8 cm

This trial may not be scientific but I believe that the general condition can be grasped.

Refer to the results of the cone-penetration test.

Plot 2



Experimental Plot

Survey date : Feb.8

5 days after irrigation

Average depth : 17.9 cm.

xi) Change of moisture ratio in course of time

Atterberg Limits

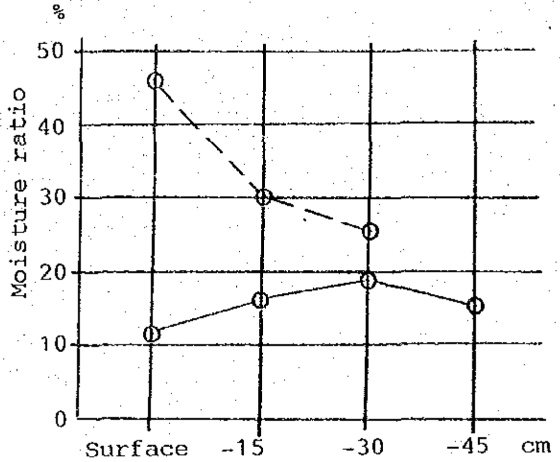
L L	P.L	P.I	K (cm/sec)
39.2	26.8	12.4	0.312×10^{-6}

Plot No.2

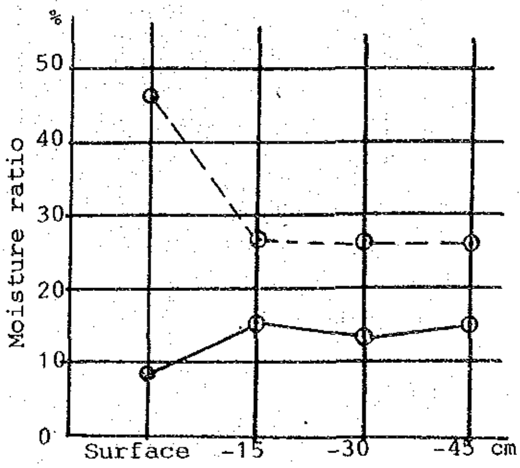
Stake No.5

O——O Before irrigation

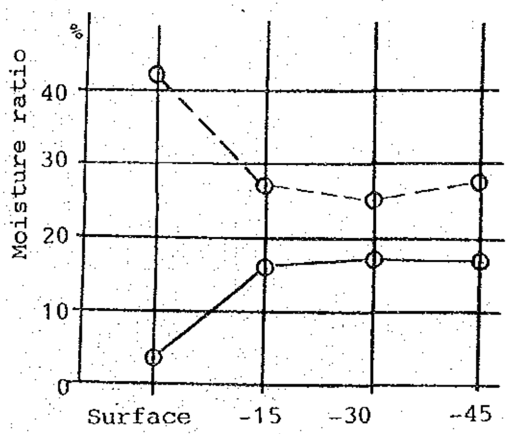
O– – –O 3 days later



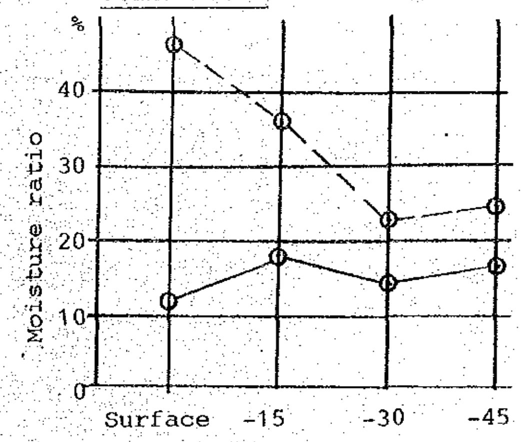
Stake No.10



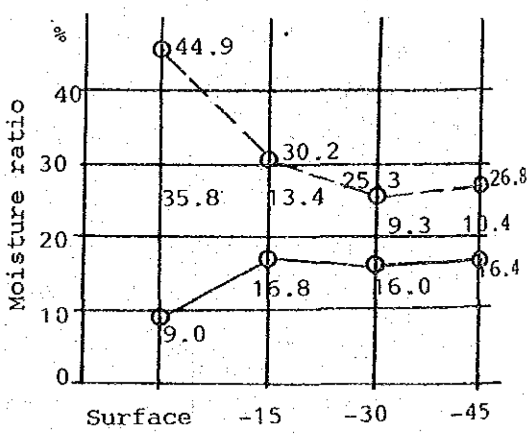
Stake No.17



Stake No.12



Average



Average increased water moisture ratio : 17.225 %

:- Test for moisture content of soils

i) Sampling place :- Plot No.2 in the Trial Farm

ii) Sampling point :- Stake No.5, No.10, No.12, No.17

iii) Remarks

$$W = \text{Moisture ratio} = \frac{ma - mb}{mb - mc} \times 100\ (\%)$$

Ma = Weight of humid soil plus container

Mb = Weight of dried soil plus container

Mc = Weight of container

Mv = Weight of water in humid soil

Ms = Weight of dried soil

iv) Results of test

- Sampling at stake No.5

- Before irrigation -

Surface	-15 cm	-30 cm	-45 cm
Container No. G-18	Container No. F-28	Container No. G-4	Container No. E-14
Ma 102.47 Mb 95.55	Ma 95.33 Mb 86.30	Ma 99.12 Mb 88.46	Ma 96.82 Mb 88.37
Mb 95.55 Mc 36.63	Mb 86.30 Mc 34.00	Mb 88.46 Mc 33.67	Mb 88.37 Mc 35.47
Mv 6.92 Ms 58.92	Mv 9.03 Ms 52.3	Mv 10.66 Ms 54.79	Mv 8.47 Ms 52.9
W = 11.74	W = 17.27	W = 19.46	W = 15.97

- 3 days later

Surface	-15 cm	-30 cm	-45 cm
Container No. E-26	Container No. G-24	Container No. E-18	Container No. F-2
Ma 98.94 Mb 78.47	Ma 96.25 Mb 82.57	Ma 104.71 Mb 89.78	Ma 96.75 Mb 77.62
Mb 78.47 Mc 34.00	Mb 82.57 Mc 37.38	Mb 89.78 Mc 33.74	Mb 77.62 Mc 33.60
Mv 20.47 Ms 44.47	Mv 13.68 Ms 45.19	Mv 14.93 Mc 56.04	Mv 18.13 Ms 44.20
W = 46.03	W = 30.27	W = 26.64	W = 41.19

-Sampling at stake No.10

- Before irrigation -

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. E-22	Container No. G-24	Container No. F-25	Container No. E-12
Ma 89.94 Mb 85.67	Ma 110.47 Mb 100.66	Ma 113.30 Mb 103.90	Ma 93.03 Mb 85.33
Mb 85.67 Mc 34.04	Mb 100.66 Mc 36.79	Mb 103.90 Mc 33.74	Mb 85.33 Mc 35.07
Mv 4.27 Ms 51.63	Mv 3.81 Ms 63.87	Mv 9.4 Ms 70.16	Mv 7.70 Ms 50.26
W = 8.27	W = 15.36	W = 13.40	W = 15.32

- 3 days later -

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. E-12	Container No. E-14	Container No. F-28	Container No. G-5
Ma 98.74 Mb 78.61	Ma 109.98 Mb 93.83	Ma 113.12 Mb 96.26	Ma 102.85 Mb 87.98
Mb 78.61 Mc 35.04	Mb 93.83 Mc 33.65	Mb 96.26 Mc 34.00	Mb 87.98 Mc 33.60
Mv 20.13 Ms 43.57	Mv 16.15 Ms 60.18	Mv 16.86 Ms 62.26	Mv 14.87 Ms 54.38
W = 46.20	W = 26.84	W = 27.08	W = 27.34

- Sampling at stake No.12

- Before irrigation -

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. G-5	Container No. E-15	Container No. F-27	Container No. F-2
Ma 103.92 Mb 96.36	Ma 95.34 Mb 86.10	Ma 108.54 Mb 99.44	Ma 122.01 Mb 109.06
Mb 96.36 Mc 33.61	Mb 86.10 Mc 35.17	Mb 99.44 Mc 34.22	Mb 109.06 Mc 33.14
Mv 7.56 Ms 62.75	Mv 9.24 Ms 50.93	Mv 9.10 Ms 65.20	Mv 12.95 Ms 75.92
W = 12.05	W = 18.14	W = 13.96	W = 17.06

- 3 days later -

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. E-22	Container No. E-29	Container No. E-20	Container No. F-27
Ma 113.54 Mb 88.62	Ma 97.61 Mb 80.88	Ma 90.48 Mb 80.10	Ma 89.41 Mb 78.24
Mb 88.62 Mc 34.49	Mb 80.88 Mc 34.31	Mb 80.10 Mc 34.73	Mb 78.24 Mc 34.25
Mv 24.92 Ms 54.13	Mv 16.73 Ms 46.57	Mv 10.38 Ms 45.37	Mv 11.17 Ms 43.89
W = 46.04	W = 35.92	W = 22.88	W = 25.45

- Sampling at stake No. 17

- before irrigation

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. G-28	Container No. G-3	Container No. E-26	Container No. G-10
Ma 107.13 Mb 104.47	Ma 112.13 Mb101.29	Ma 92.12 Mb 83.64	Ma 99.27 Mb 89.71
Mb 104.47 Mc 34.20	Mb 101.29 Mc 35.00	Mb 83.64 Mc 33.94	Mb 89.71 Mc 34.02
Mv 2.66 Ms 70.27	Mv 10.84 Ms 65.29	Mv 8.48 Ms 49.70	Mv 9.56 Ms 55.69
W = 3.79	W = 16.35	W = 17.06	W = 17.17

- 3 days later -

Surface	- 15 cm	- 30 cm	- 45 cm
Container No. F-20	Container No. F-9	Container No. F-25	Container No. G-3
Ma 95.75 Mb 77.62	Ma 106.82 Mb 90.96	Ma 95.68 Mb 83.42	Ma 106.25 Mb 90.86
Mb 77.62 Mc 33.60	Mb 90.96 Mc 33.45	Mb 83.42 Mc 33.70	Mb 90.86 Mc 35.00
Mv 18.13 Ms 44.20	Mv 15.86 Ms 57.51	Mv 49.72 MS 12.26	Mv 15.39 Ms 55.86
W = 41.19	W = 27.58	W = 24.66	W = 27.55

xii) Bearing capacity

:- Survey date

1 st : Feb.7, 5 days after water supply

2 nd : Feb.14,12 days after water supply

3 rd : Feb.22,20 days after water supply

4 th : Mar.1, 27 days after water supply

:- Field condition before water supply

	Experimental plot No.1	Experimental plot No.2
Area	7,850 m^2	7,850 m^2
Drained out water	Nov. 26,1982	Nov. 26, 1982
Harvesting	Dec. 14,1982	Dec. 14, 1982
1 st rotavating	Jan. 4,1983	no
2 nd rotavating	Jan. 11,1983	no
Field level	well	well

:- Water supply

	Plot No.1	Plot No.2
Date	Feb. 1, 2, 1983	Feb. 3, 1983
Quantity	1,080 m^3(137.6 mm)	1,296 m^3(165.1 mm)

:- Field preparation after water supply

	Plot No.1	Plot No.2
Rotavating	-	Feb. 9, 1983
Puddling	Feb. 9,1983	Feb.11, 1983
Planking	Feb. 23,1983	Feb.23, 1983

:- Equipment

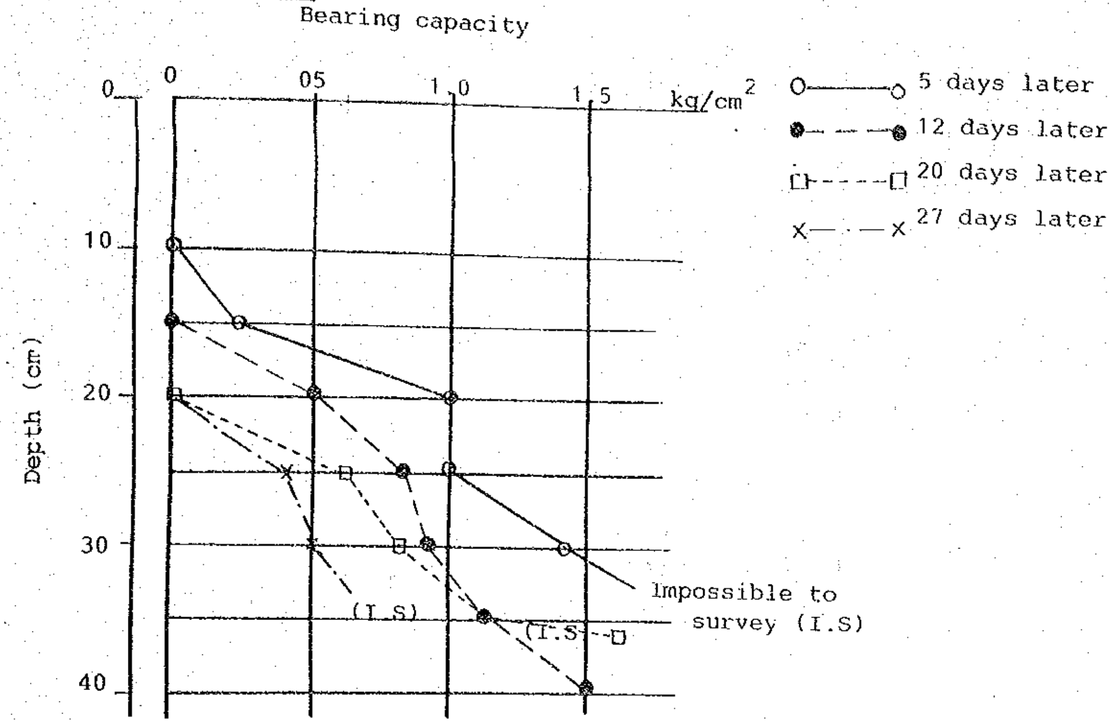
Cone penetrometer

Top cone : 30

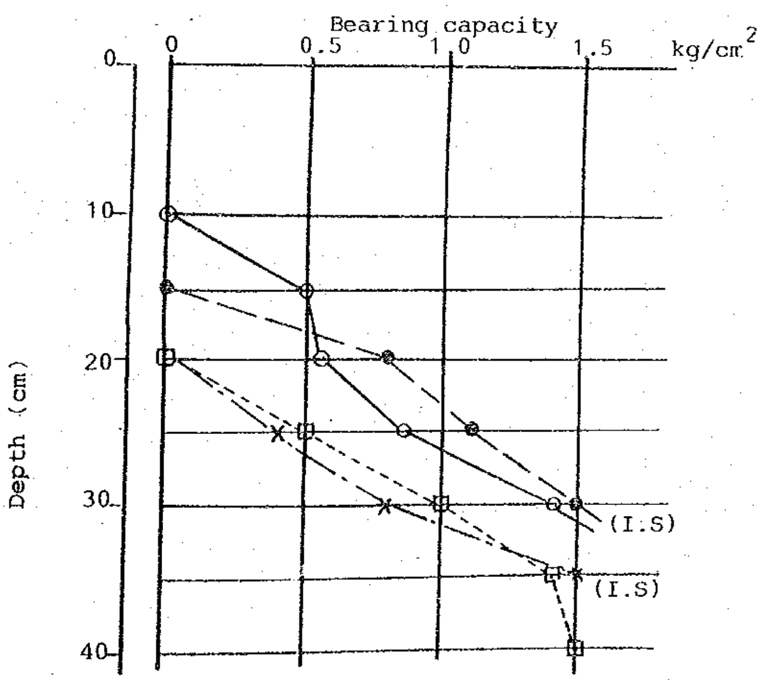
:- Result

Plot No.1

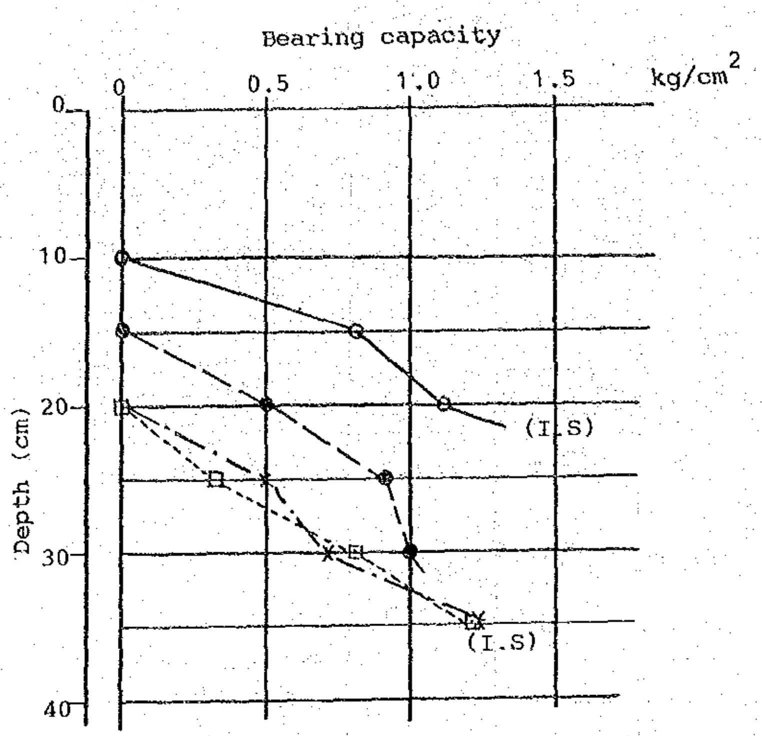
Stake No.5



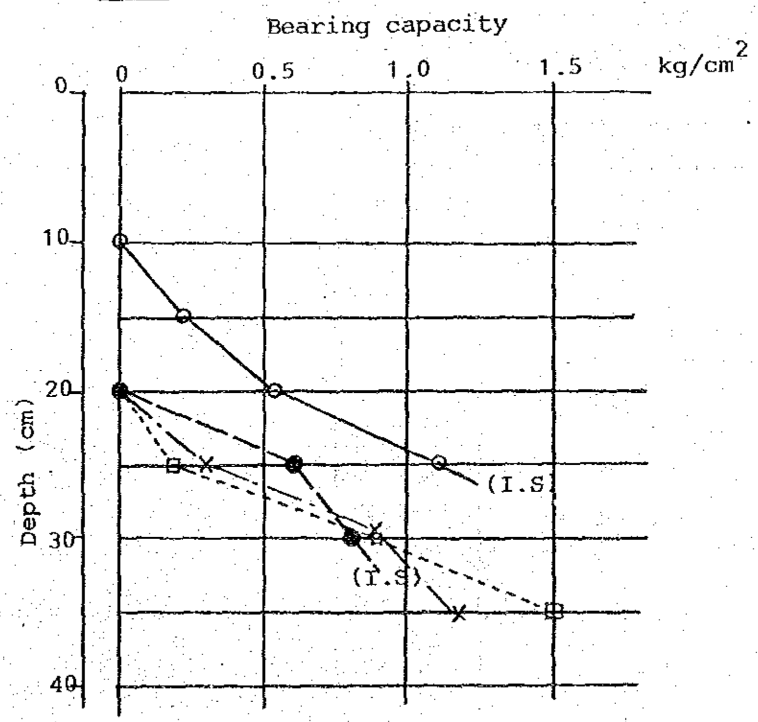
Stake No.10



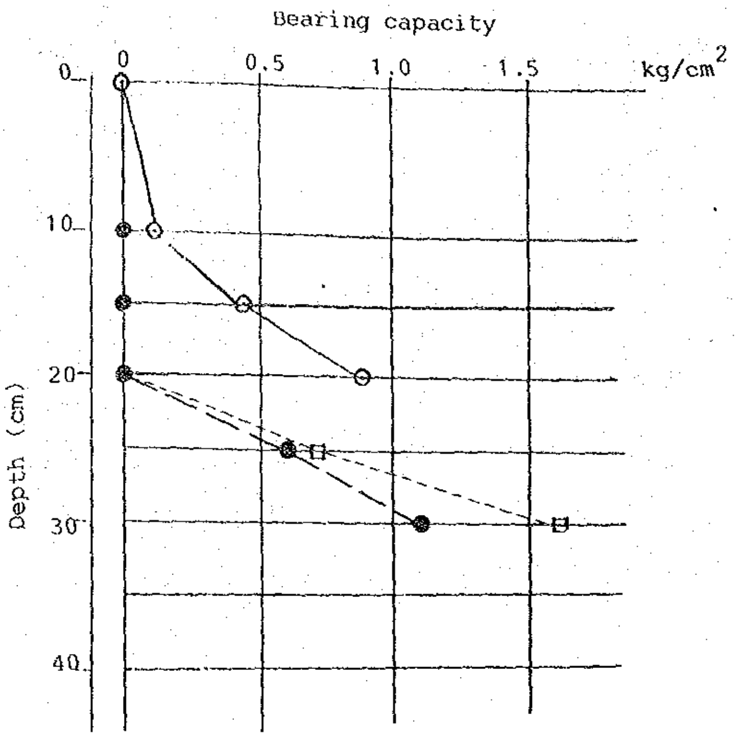
Stake No.12



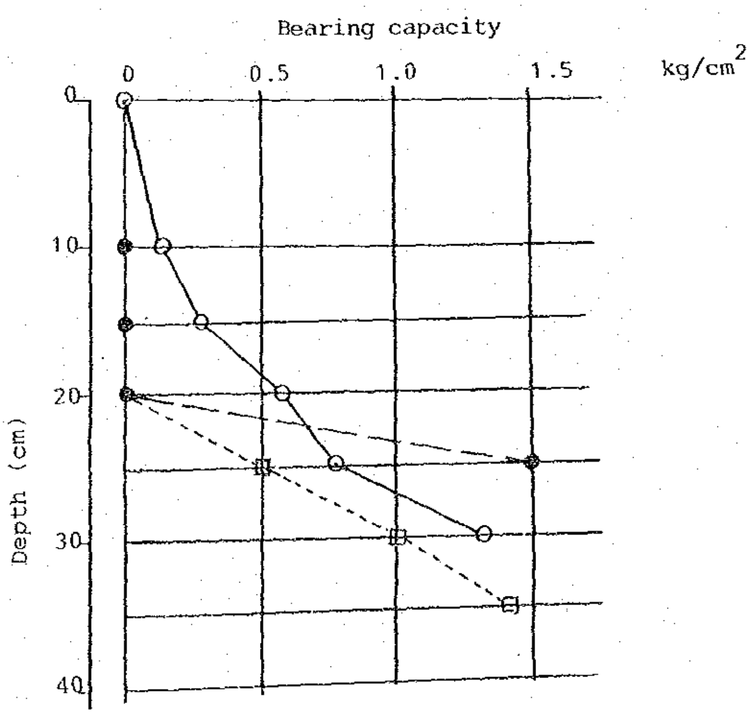
Stake No.17



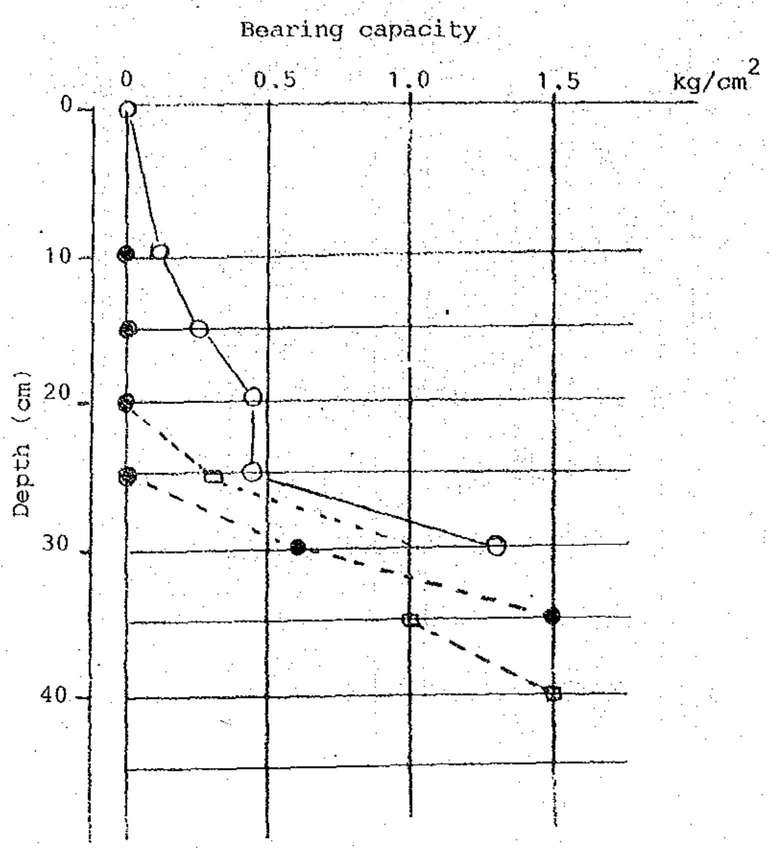
Stake No.5



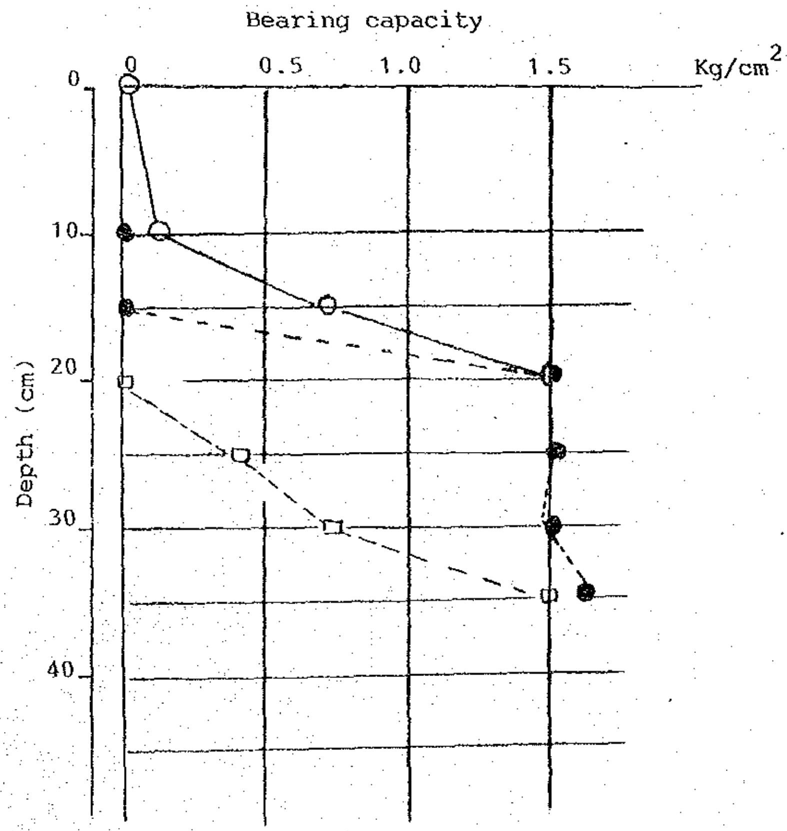
Stake No.10



Stake No.12



Stake No.17



5. Result of Bearing capacity survey

Field No.	Stake No.	- 10 cm.				- 15 cm.				- 20 cm.				- 25 cm.				-30 cm.				- 35 cm				- 40 cm.				- 45 cm.			
		1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1		5	0	0	0	2.0	0	0	0	10.0	5.0	0	0	10.0	8.0	6.0	4.0	14.0	9.0	8.0	5.0	-	11.0	11.0	-	-	15.0	-	-	-	-	-	-
		10	0	0	0	5.0	0	0	0	5.5	8.0	0	0	8.5	11.0	5.0	4.0	14.0	15.0	10.0	8.0	-	-	14.0	15.0	-	-	15.0	-	-	-	-	-
		12	0	0	0	8.0	0	0	0	11.0	5.0	0	0	-	9.0	3.0	5.0	-	10.0	8.0	7.0	-	10.0	12.0	12.0	-	-	-	-	-	-	-	-
		17	0	0	0	2.0	0	0	0	5.5	0	0	0	11.0	6.0	2.0	3.0	-	8.0	9.0	9.0	-	-	15.0	12.0	-	-	-	-	-	-	-	-
2		5	1.0	0	0	4.5	0	0	0	8.5	0	0	0	-	6.0	7.0		-	11.0	16.0		-	-	-		-	-	-		-	-	-	
		10	1.0	0	0	2.5	0	0	0	5.5	0	0	0	7.5	15.0	5.0		13.0	-	10.0		-	-	14.0		-	-			-	-	-	
		12	1.0	0	0	2.5	0	0	0	9.5	0	0	0	9.5	0	3.0		13.0	6.0	10.0		-	15.0	10.0		-	-	15.0		-	-	15.0	
		17	1.0	0	0	7.0	0	0	0	15.0	15.0	0	0	-	15.0	4.0		-	15.0	7.0		-	16.0	15.0		-	-	15.0		-	-	-	

REmarks :- Mark - : Impossible to survey

5. Study of the cracks appearing in paddy fields

Many cracks appear on the surface after drainage of paddy fields because of silty-clay soil. These cracks cannot be neglected in the case of considering preparatory water. On the other hand, the surface of the paddy field becomes harder and harder as time goes on and it makes plowing impossible.

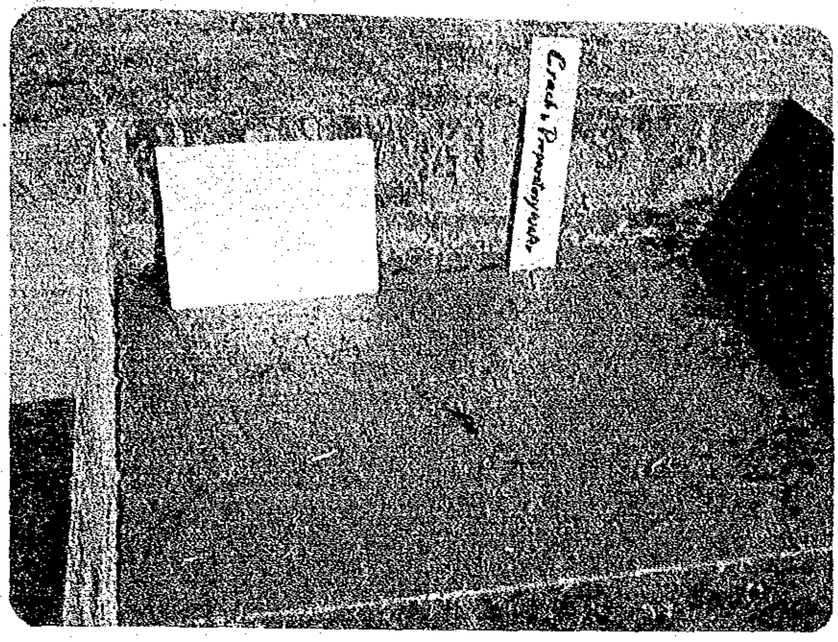
In order to make clear the structure of the cracks. The following thing was tried.

1) Stell box test

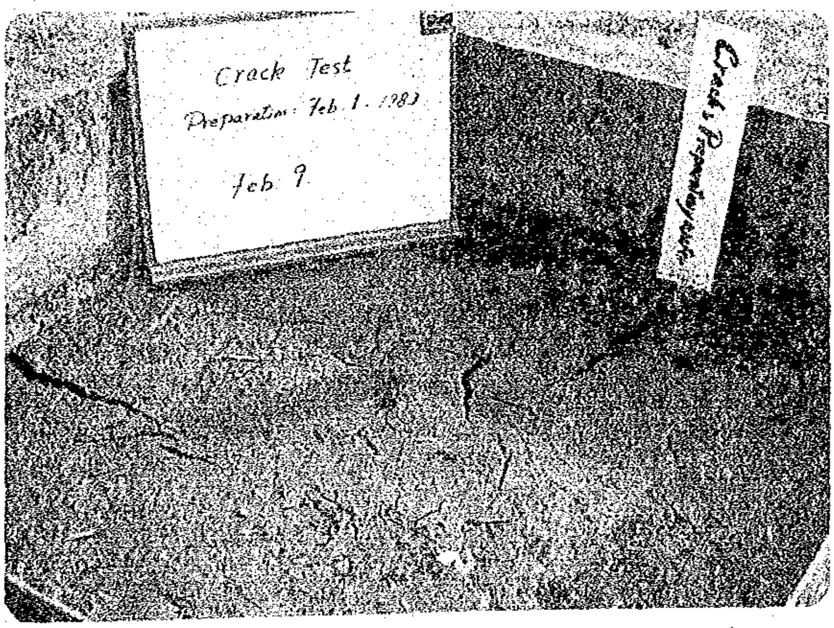
In order to measure the rough volume of cracks, a stell box with a bottom was used. The size of the box used in this test was "1 m x 1 m x 0.7 m"

Paddling was carried out in the box on Feb.1st and it was kept as it was for five days, after that standing water was drained out of the holes opened near the bottom.

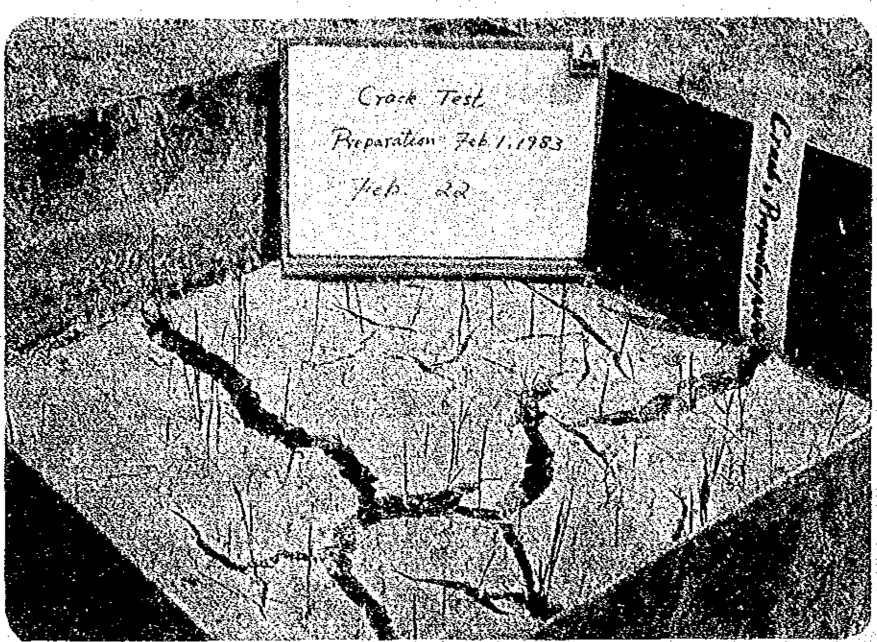
Situation of the soil surface just after drainage

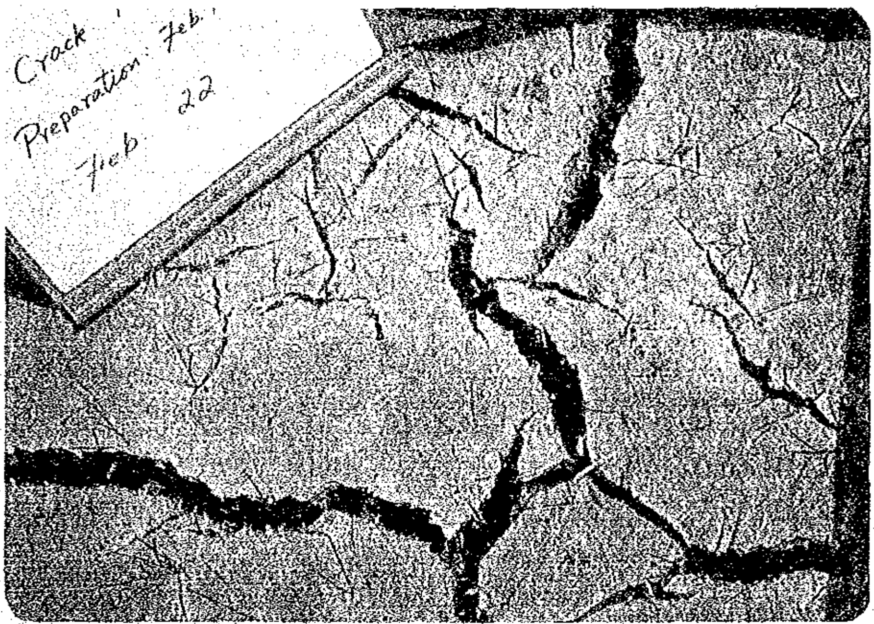


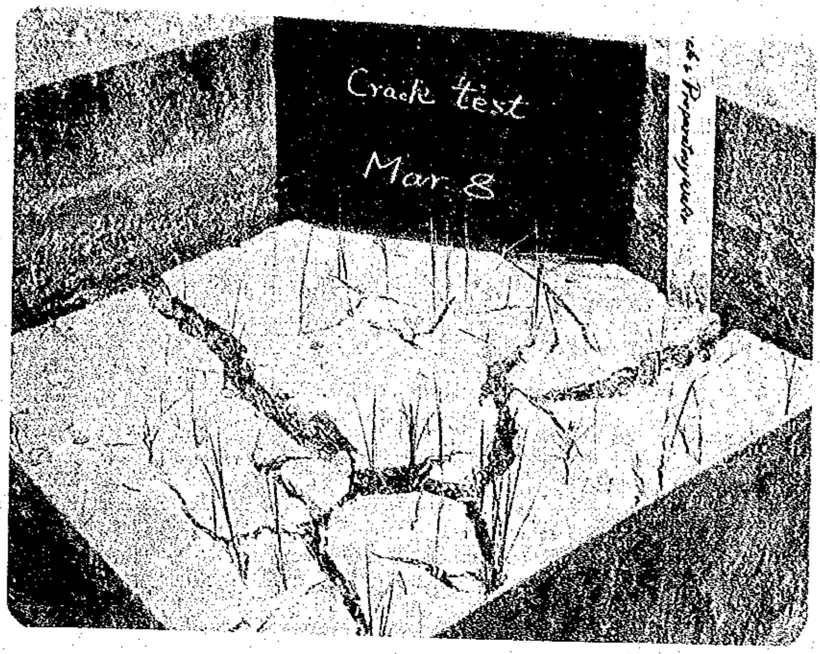
Some cracks appeared 4 days later

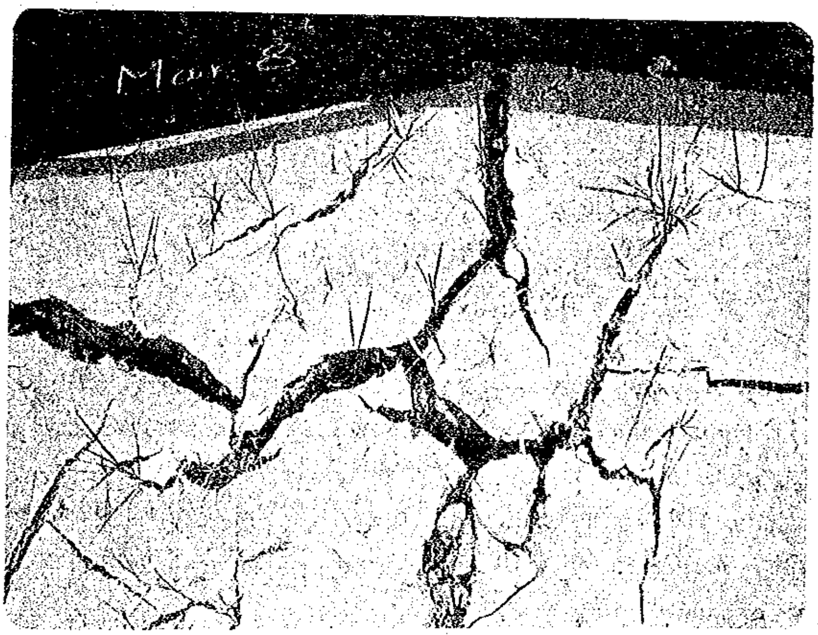


21 days after drainage






Crack test
Mar. 8


Mar. 8

:- preparation for the survey

- soil depth : 50 cm (volume 500 l)
- paddling in the box : Feb.1, 1983.
- drainage of standing water : Feb.5

:- Assumption of cracks'volume

On Mar.16, 39 days after the drainage of the standing water, the cracks were filled up with 62 l.

- Supplied water to fill cracks : 62 l
- Assumption of porosity

$$e = \frac{Giew}{t} \left(1 + \frac{w}{100}\right) - 1 = \frac{Gsew}{d} - 1$$

e = void ratio

Gs = specific gravity = 2.60 see page 29

Cw = density of water = 1.00

w = moisture ratio (neglect)

Ct = humid density of soil

v = volume (cm^3)

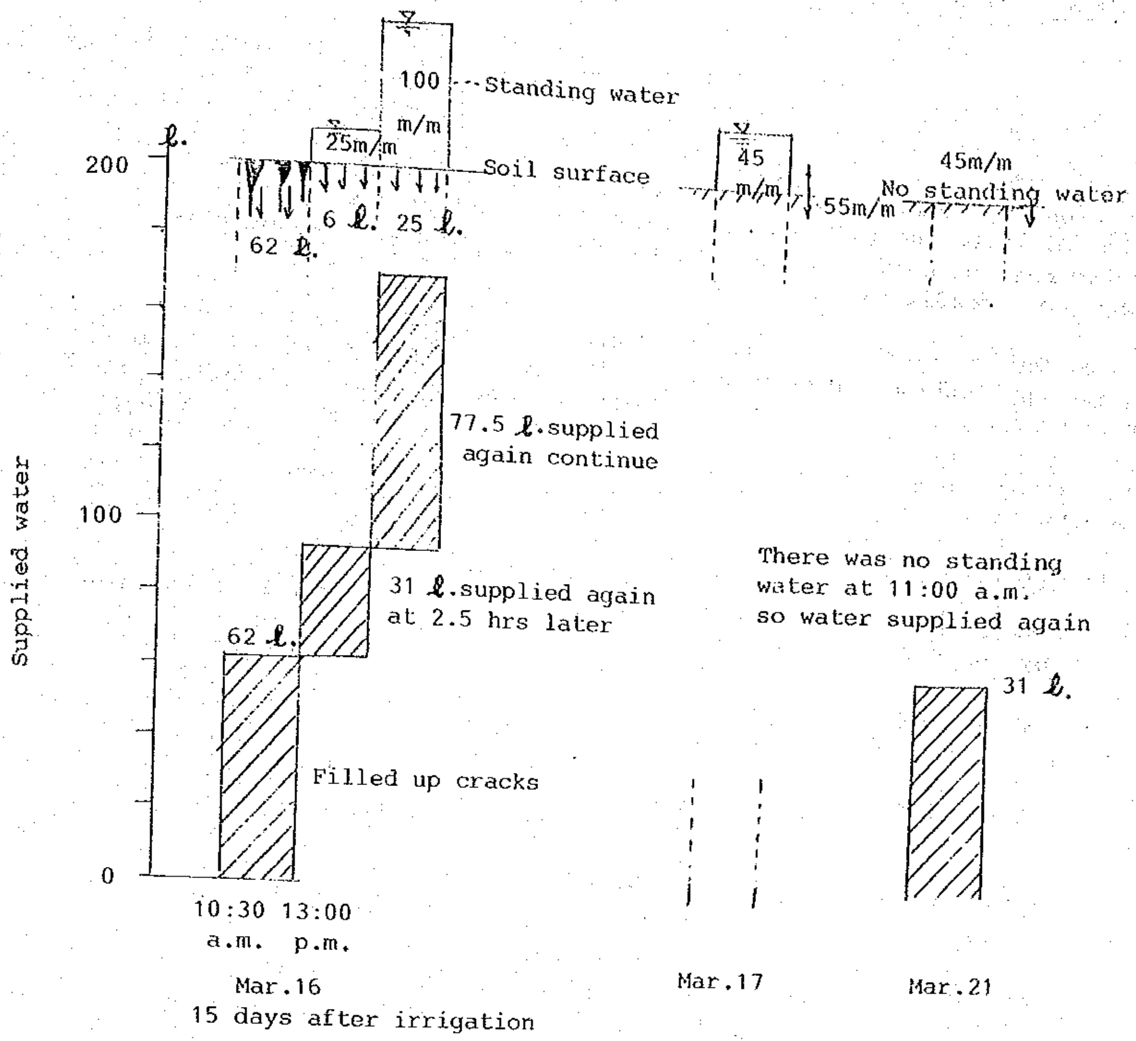
Cd = dry density of soil = 1.598 g/cm^3

$$e = \frac{2.60 \times 1.00}{1.598} - 1 = 0.627$$

porosity (Voidage) n:

$$n = \frac{e}{1 + e} \times 100\% = \frac{0.627}{1 + 0.627} \times 100 = 38.5\%$$

Although water was supplied rapidly to fill up the cracks if we take it that 20% of the supplied water was absorbed by the soil, the capacity of the cracks would be about 50 l/m^2 (80 m^3/rai, 500 m^3/ha) This value is proportionate to 50 mm/ha in depth.
However, once soil absorbs water, the cracks are naturally closed by the expanded soil.
Therefore, it is too hard to analyze this matter.



Total quantity of supplied water : 201.5 l

According to this trial it was observed that the irrigation water is required about 200 l (200 mm) for ploughing and will be required more 40-50 l (40~50 mm) for puddling and planking.

K. Computation formulas of the peak water requirement for paddy (translation)

Original report (Thai version) : by Mr.Direk Tongram

In order to control the use of water by farmers especially about the water distribution in the ricefield, it is important that the irrigation system must be perfectly designed and must be related to climatic and geographic conditions.

Water delivery (all the time, interval or as needed by farmers) and irrigation application are used as the bases for calculating for water requirement. Generally rice water requirement is used for basic estimation since rice uses a lot of water . Water balance, which is delivery water is equal to water requirement for total operation, is also used in calculation. Formulas or methods that use for irrigation system designing are as followed:

1. General principles

Water which will be delivered into the ricefield can be calculated by the following formula

$$Q = \frac{A.D}{86,400} \times \frac{1}{(EFF.)_1} \quad \ldots\ldots(1)$$

$$Q \text{ at Farm Turnout} = \frac{A.D}{86,400} \times \frac{1}{(EFF.)_1 (EFF.)_2} \quad \ldots\ldots(2)$$

$$Q \text{ at Head Gate} = \frac{A.D.}{86,400} \times \frac{1}{(EFF.)_1 (EFF.)_2 (EFF.)_3} \quad \ldots\ldots(3)$$

where :

$(EFF.)_2$ = water delivery efficiency in secondary canal, decimal

$(EFF.)_3$ = water delivery efficiency in tertiary canal, decimal.

Q = flowrate, m^3/sec

A = area to be irrigated, m^2

D = water depth of irrigation application, m/day
ET + P - R

ET = evapotranspiration, m/day

P = percolation and seepage losses, m/day

R = effective rainfall, m/day

(EFF.) = efficiency of using water in the ricefield, decimal
= 1 - L

L = water losses in the ricefield, decimal

The depth of irrigation water per day (D) for ricefield preparation can be estimated from the following formula

$$D = \frac{C - R_1 + (P + E) N}{N} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

WHERE:

E = evaporation rate, m/day

N = days to irrigate water into the ricefield

R_1 = rainfall during irrigation period, m

C = water for field preparation (m)

which came from calculation or experimentation

Calculation for rotational irrigation

$$Q = \frac{A.Dr.}{T} \cdot \frac{1}{EFF.} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

WHERE:

Q = flowrate, m^3/sec. (Normally the flowrate depends on the diameter of the pipe)

A = area to be irrigated, m^2

Dr = water depth of each irrigation applications, m

= $D.P_r$ = $(ET + P - R)\ P_r$

P_r = rotational interval

T = time required to deliver water into the field

R = average rainfall during rotational interval, m/day

The sizes of rice irrigation canals can be calculated from the following formulas which are developed for the maximum efficiency and results.

2. Conventional Formula

2.1 Taiwan's formula

The conventional formula used by the Provincial Water Conservancy Bureau of Taiwan can be written as :

$$Q_{max} = \left(\frac{AD_s}{N} + AD_t\right) \frac{1}{1 - L} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$Q_{max} = \left(\frac{AD_s}{NT} + \frac{AD_t}{T}\right) \frac{1}{1 - L} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6a)$$

WHERE:

Q_{max} = maximum discharge required, m^3/day

A = area to be irrigated , m^2

A. Prepared area at day N

B. Water requirement for field preparation

C. Water requirement for rice seedling (increase every day)

D. Total water requirement

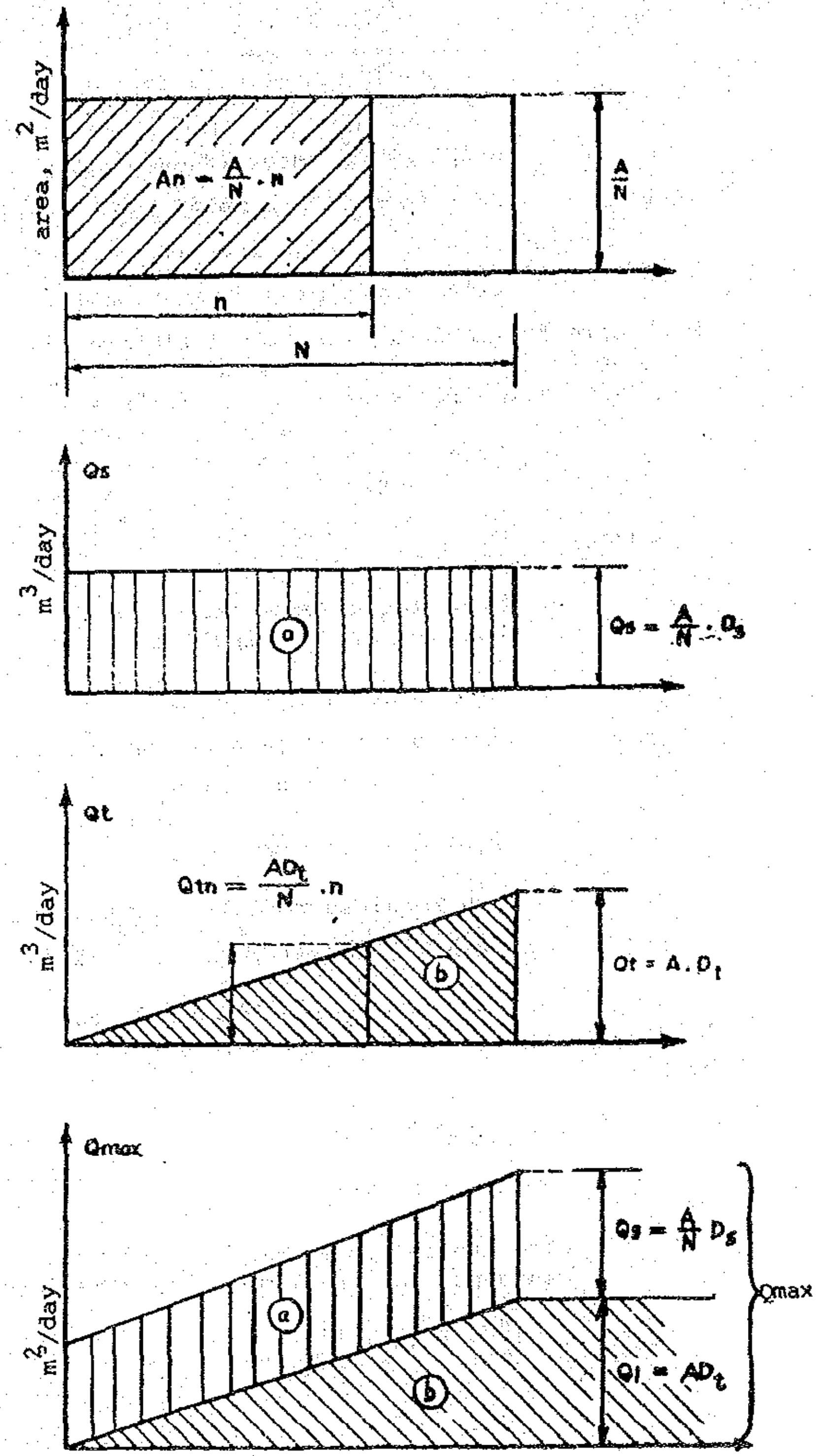


Figure 1-4 Water requirement according to the design of irrigation system.

D_t = water requirement after transplanting field, hereafter called maintenance water, m/day

D_s = land-soaking and standing water application, m

= $D_{ss} + D_{st}$

D_{st} = standing water requirement, m

D_{ss} = soil saturation water requirement, m

= depth of soil saturation x soil void x (1-soil moisture content)

N = time required to prepare area A , days

T = seconds inaday ≐ 86,400 sec.

L = conveyance losses, decimal

From Equation 6, water requirement will increase every day until the last day (day N) of field preparation which the water requirement is maximum. After that the water requirement is sharply reduced and just enough for feeding the rice seedling

That is : $Q_t = AD_t \left(\frac{1}{1-L} \right)$

If irrigation is done as Equation 6, delivery water will increase everyday. Delivery water at specific day can be calculated from

$$Q_n = \left(\frac{AD_s}{N} + \frac{AD_t . n}{N} \right) \frac{1}{1-L}$$

Q_n = water requirement for rice at day N

N = date at which the water requirement is maximum

2.2 Chow'S formula

Chow gave a revised form of Equation 6 as follows:

$$Q = \frac{A}{8.64} \left(\frac{d_s}{P_s} + \frac{d_r}{P_r} \right) \frac{1}{1-L} \quad \text{.......................... (7)}$$

where:

Q = flowrate, m^3/sec

A = total area, hectares (10,000 m^2)

d_s = land-soaking and standing water application,m

= standing water requirement, m + soil saturation water requirement, m

d_r = maintenance water depth of each rotational irrigation application, m

P_r = rotational interval, days

P_s = time required to prepare area A, days

L = conveyance losses, decimal

when $d_r = D_t \times P_r$, Equation 6 = Equation 7

3) Japan's formula

$$R_{max} = \frac{10A}{n} \left(S + (n-1)d \right) \frac{1}{1 - L} \quad \text{.........................(8)}$$

where:

R_{max} = maximum discharge required, m^3/day

A = area, hectares (10,000 m^2)

d = daily water requirement, mm/day

S = water requirement for field preparation

= standing water requirement + soil saturation water requirement

n = time required to prepare area A, days

L = conveyance losses, decimal

2.3 Goor-Zijlstra-Wen Formula

1) Van de Goor and Zijlstra's formula

Goor and Zijlstra developed the following formula while working at FAO in Malaysia from October 1971 to April 1973 and the publication was in 1978.

$$I = \frac{M_e^{MT/s}}{e^{MT/s-1}} \quad \text{...................................(9)}$$

where:

M = water requirement, mm/day

I = water requirement for field preparation, mm/day

T = time required for field preparation, days

s = water requirement for field preparation, mm

Equation 9 will be equal to Equation 10

2) Wen's formula

Wen published the following equation in 1972. The publication was based on his M.S. thesis which was completed in 1970

$$Q_m \; (m^2/day) = \frac{AD_t}{\left\{(1-e^{-(D_t/D_s)\cdot N}\right\}} \cdot \frac{1}{1-L} \quad \ldots\ldots\ldots\ldots(10)$$

$$Q_m \; (m^2/day) = \frac{AD_t}{T\left\{1-e^{-(D_t/D_s)\cdot N}\right\}} \cdot \frac{1}{1-L} \quad \ldots\ldots\ldots\ldots(10a)$$

where:

Q_m = water requirement to prepare area A = $Q_s + Q_t$

= maximum water requirement

A = area to be irrigated, m^2

D_t = water requirement for transplanting including percolation (ET + P), m/day

D_s = depth of water requirement for field preparation

N = days to prepare the entire area

T = second in a day = 86,400 sec.

L = conveyance losses, decimal

e = base of natural logarithms = 2.718282

Main water is used for field preparation in the first day. Later the areas are reduced and part of water will be delivered to feed the rice seedling.

Y_o = first day area

$$= \frac{AD_t}{D_s \left\{1-e^{-(D_t/D_s)\cdot N}\right\}}$$

Y_n = area at day N

$$= Y_o \frac{1}{e(D_t/D_s)\cdot N}$$

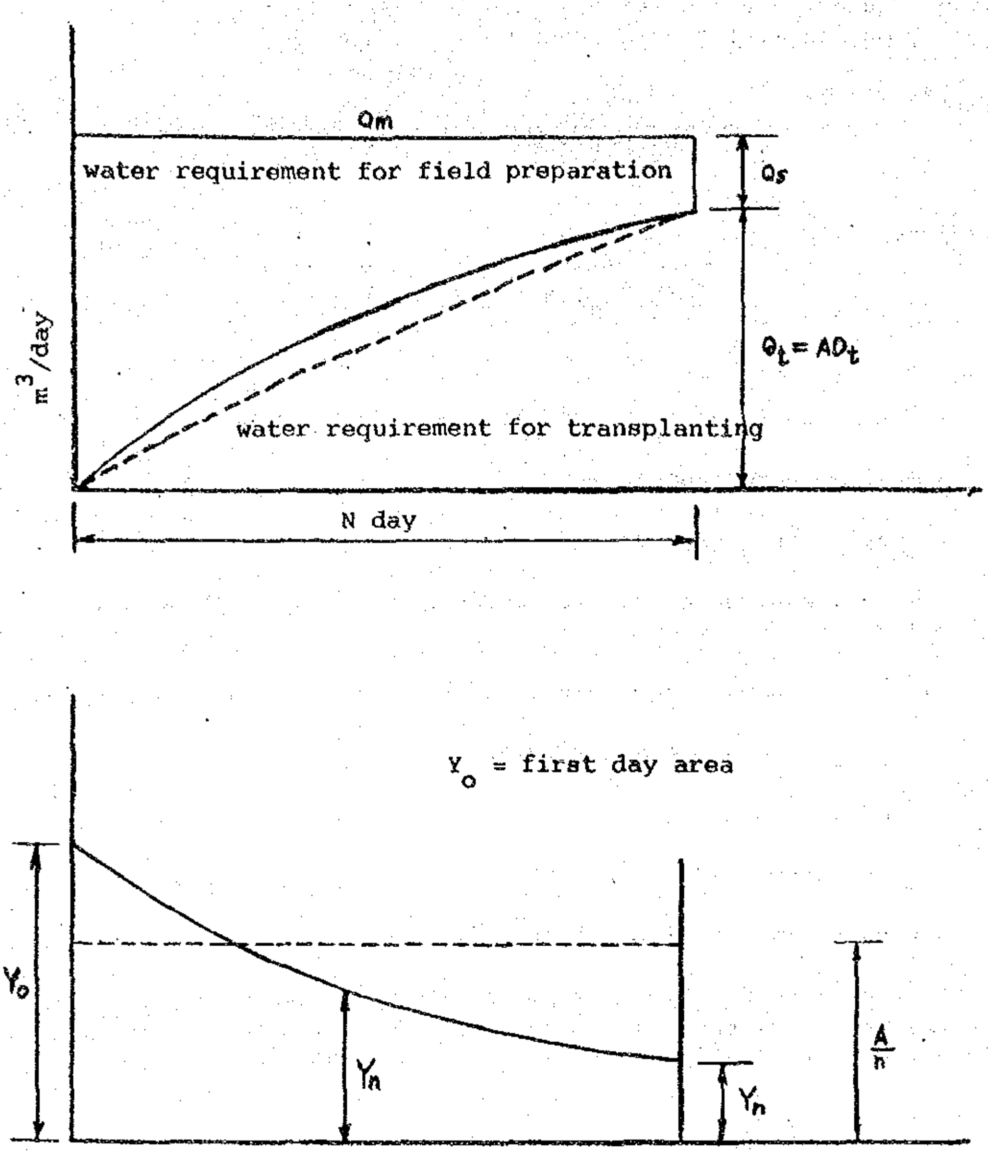


Figure 5 Water requirement according to Wen's idea

3) Cheng's formula

In case of irrigation for field preparation more than one day, Cheng introduced new following formula.

$$Q = \frac{A}{8.64}\left[\frac{d}{1 - K^{n}}\right]\frac{1}{1 - L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

where :

$$K = \frac{\frac{D}{r} - \frac{d}{2}}{\frac{D}{r} + \frac{d}{2}}$$

Q = flowrate, m^3/sec

A = area to be irrigated, m^2

d = daily water requirement, m/day

D = water requirement for field preparation,m

n = time required to prepare area A, days

L = conveyance losses, decimal

r = time required for field preparation for each area, days

If r = 1, result from Equation 11 = result from Equation 10

3. Improved Formula

1) J.K. Wang formula

Wang developed the following formula which was called Improved Formula.

$$Q = \frac{AD_t}{1 - \left(1 - \frac{D_t \cdot S}{D_s}\right)^{n}} \cdot \frac{1}{1 - L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Q = flowrate, m^3/day

A = area to be irrigated, m^2

D_t = daily water requirement for field preparation, m

D_s = total water requirement for field preparation , m

= soil saturation water requirement standing water requirement

S = rotational interval, days

n = number of rotational periods days

$\frac{N}{S}$ = must be in full number

N = time required for complete field preparation, days

2) Kertpitak and Kayan kannavee'S formula

Kertpitak and Kayankannavee developed the idea for an irigation in the latural or secondary canal level. Their principle are ....(suppose this is equation 13)

- transplanting starts after field preparation or 2 weeks after field preparation.
- rice coefficient obtained from the experimentation of RID is determined to use according to the stage of growth in stead of using other formulas or method which the crop coefficient is 1.0 at all time.
- set the area in parts

(One who interested in this method, please see " Calculation for rice water requirement in zone level and calculation for canal capacity by vice professor Chalong Kertpitak and Chivat Kayankannavee")

4. Summary and suggestion

The design of irrigation system should be considered

1) Delivery methods

1.1 delivery at all time
1.2 interval delivery
1.3 delivery as needed by farmers

2) The important factors for calculation are:

2.1 consumption use value = evaporation + transpiration

2.2 percolation losses value

2.3 water requirement for field preparation

- evaporation
- percolation
- land soaking
- water layer

2.4 Field preparation depends on

- seedling age
- how fast the farmer can do for each day

3) In designing the canal capacity of irrigation system, the maximum water requirement (No rainfall) for field preparation is in the last period since part of water is for field preparation and another part is for transplanting.

Chalong's idea

- water requirement for field preparation is equal to that of transplanting
- area is set into 3 parts and each part takes 2 weeks to finish (for central region) days for complete field preparation is 42 days (N = 42)
- transplanting begins after finished the field preparation in each area.

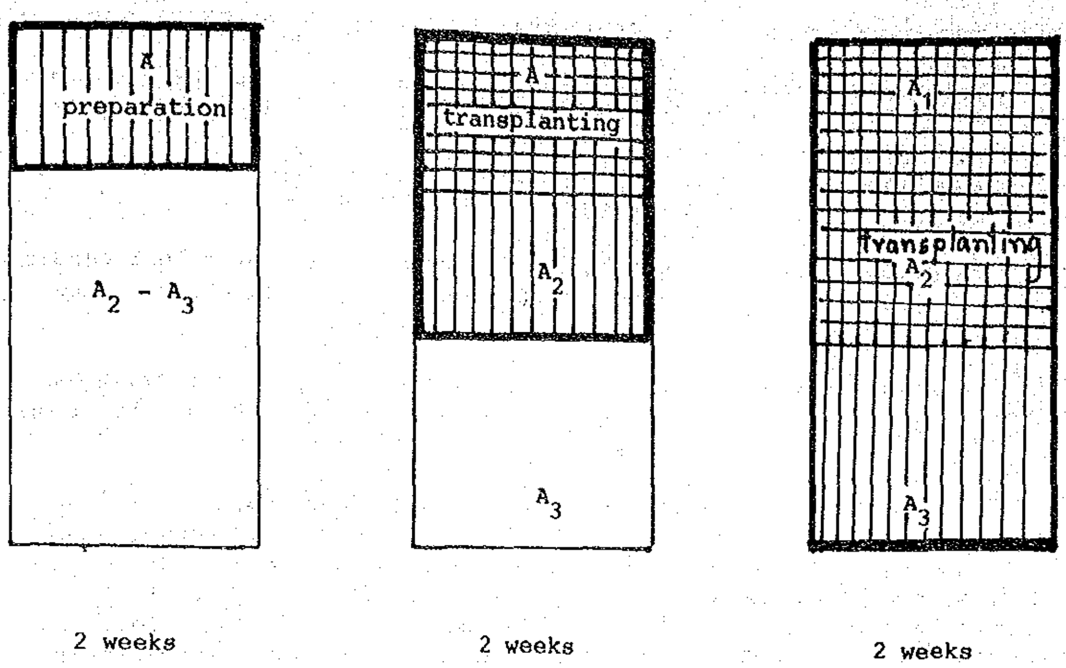


Figure 6 : Chalong's idea in field preparation and transplanting

Therefore, water requirement depends on time required for field preparation. It is short, the water requirement will be very high for each day.

Formula characteristics

Equations (6)(7)(8) - rate of increasing the areas in the period of field preparation is fixed and no rainfall

Equations (6)(7) - plants have used water since first day.

but Equations(8) - plants begin to use water in the following day.

Equations (9)(10) - areas are gradually reduced as the expotential curve and plants can immediately use water.

Equations (11) - field preparation is as Equations 9, 10 but adding interval irrigation

Equations (12) - irrigation is set in parts for actual condition in preparing the areas and plants use water in the next interval period.

Equations (13) - set preparation areas in parts as Equations 12 but using the rice coefficient obtained from experimentation.

The results from comparing the formulas (see Appendix A) for example Taiwan's formula, Wen's formula (see Appendix B), Wang's formula and Kertpitak and Kayan Kannavee's formula (see Appendix C) showed that Kertpitak and Kayan Kannavee's formula was better than others because they used climatic data and rice coefficient according to the stage of growth in determining the estimated water requirement.

Comparison on calculation for water requirement for field preparation

Water requirement for field preparation	Q max by Taiwan's formula m^3/sec	Q m by Wen's formula		Qm by Chalong's method			Wang's method				Remark
		m^3/sec	less than Q max %	m^3/sec	less than Qmax %	less than Wen's %	m^3/sec	less than Qmax %	less than Wen's %	more than Chalong's %	
200	0.254	0.196	30	0.179	42	9	0.185	37	6	3	A = 1,000 rai
250	0.280	0.219	28	0.201	39	8	0.207	35	6	3	N = 42 days
300	0.306	0.243	26	0.224	37	8	0.230	33	6	3	D_t = 6.89 mm/day
350	0.332	0.267	24	0.248	34	7	0.254	31	5	2	E_c = 1 - L.
400	0.357	0.292	22	0.273	31	7	0.279	28	5	2	= 0.85

Appendix B : Example of calculation by Wen's formula

Wen's formula

$$Q_m = \frac{A_n \times D_t}{8.64\ E_c \left\{1-e^{-(D_t/D_s).N}\right\}}$$

where:

Q_m = flowrate, M^3/sec

A_h = area to be irrigated, hectares = 160

D_s = depth of water requirement for field preparation =350 mm

D_t = water requirement for transplanting, m/day

= 0.00589 + 0.0010 = 0.00689 m/day

N = days to prepare the entire area, days

= 42

e = 2.718

E_c = delivery efficiency in dry season

= 0.85

therefore

$$Q_m = \frac{160 \times 0.00689}{8.64 \times 0.85 \left\{1-e^{-(.00689/0.350) \times 42}\right\}}$$

= 0.267 m^3/sec.

Appendix C Example of calculation by Kertpitak and Kayankannavee method

Calculation for area in each period

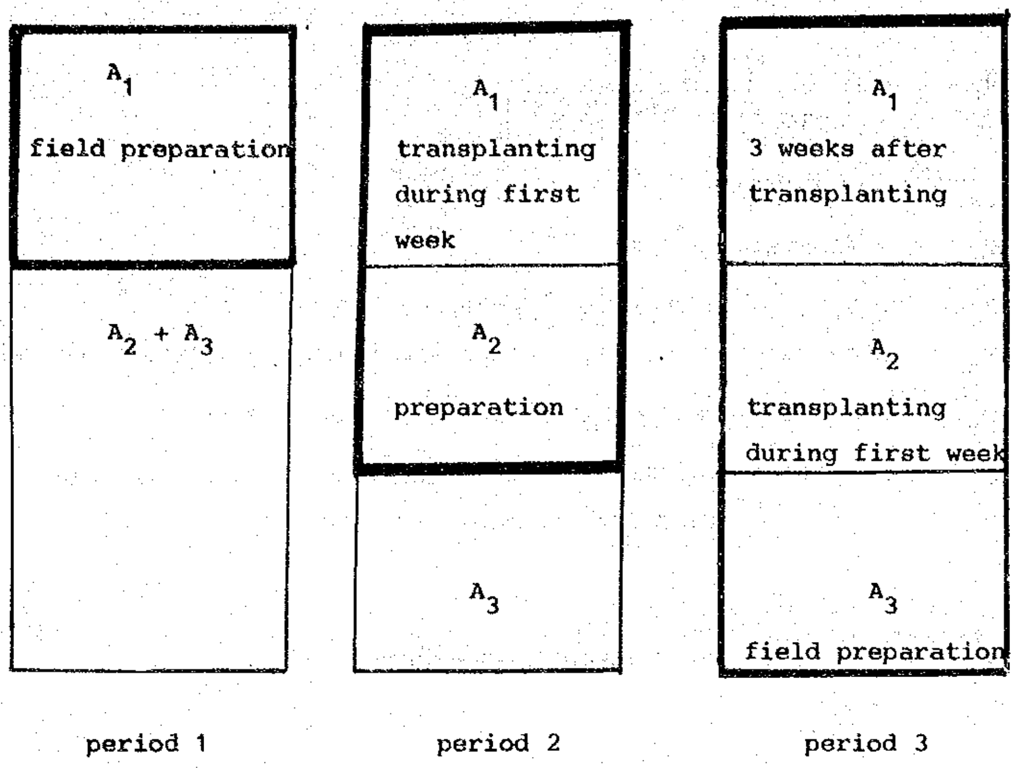


Figure 1 : Field preparation and transplanting

Let A_1 = field preparation in first period

A_2 = field preparation in second period

A_3 = field preparation in third period

A = total area = $A_1 + A_2 + A_3$

Water requirement for field preparation obtained from Samchuk station = 350 mm

$\therefore$ water requirement for field preparation = $\frac{350}{14}$ = 25 mm/day = W_L

where : W_D = rate of percolation/day

W_{E1} = Potential Evapotranspiration x rice coefficient in first week

W_{E2} = Potential Evapotranspiration x rice coefficient in second week

W_{E3} = Potential Evapotranspiration x rice coefficient in third week

W_{E4} = Potential Evapotranspiration x rice coefficient in forth week

W_{E5} = Potential Evapotranspiration x rice coefficient in fifth week

Water requirement in the first period

$$= A_1 W_L + A_1 W_D \quad \cdots\cdots (1)$$

Water requirement in the second period

$$= A_2 W_L + A_1 W_{E1} + (A_1 + A_2) W_D \quad \cdots\cdots (2)$$

Water requirement in the third period

$$= A_3 W_L + A_1 W_{E3} + A_2 W_{E1} + (A_1 + A_2 + A_3) W_D \quad \cdots\cdots (3)$$

Total water requirement

$$= A_1 W_{ES} + A_2 W_{E3} + A_3 W_{E1} + A W_D \quad \cdots\cdots (4)$$

Total area

$$A = A_1 + A_2 + A_3 \quad \cdots\cdots (5)$$

Equation 1 = Equation 2 = Equation 3 = Equation 4

If Equation 1 = Equation 2 therefore;

$$A_1 W_L + A_1 W_D = A_2 W_L + A_1 W_{E1} + A_1 W_D + A_2 W_D$$

$$\therefore A_1 = \frac{A_2 (W_L + W_D)}{(W_L - W_{E1})} \quad \cdots\cdots (6)$$

If Equation 2 = Equation 3 therefore;

$$A_2 W_L + A_1 W_{E1} + A_1 W_D + A_2 W_D = A_3 W_L + A_1 W_{E3} + A_2 W_{E1} + A_1 W_D + A_2 W_D + A_3 W_D$$

$$A_3 (W_L + W_D) = A_2 (W_L - W_{E1}) + A_1 (W_{E1} - W_{E3})$$

$$\text{or } A_3 = \frac{A_2 (W_L - W_{E1})}{(W_L + W_D)} + \frac{A_2 (W_L + W_D) \cdot (W_{E1} - W_{E3})}{(W_L - W_{E1}) \cdot (W_L + W_D)}$$

$$A_3 = \frac{A_2 (W_L - W_{E1})}{(W_L + W_D)} + \frac{A_2 (W_{E1} - W_{E3})}{(W_L - W_{E1})}$$

$$= A_2 \frac{(W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D)}{(W_L + W_D) \cdot (W_L - W_{E1})} \quad \cdots\cdots (7)$$

Substitute values from Equations 6 and 7 in Equation 5

$$A = \frac{A_2 (W_L + W_D)}{(W_L - W_{E1})} + A_2 + \frac{A_2 (W_L - W_{E1})}{(W_L + W_D)} + \frac{A_2 (W_{E1} - W_{E3})}{(W_L - W_{E1})}$$

$$= \frac{A_2 \left[(W_L + W_D) + (W_L - W_{E1}) \cdot (W_L + W_D) + (W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D) \right]}{(W_L - W_{E1}) \cdot (W_L + W_D)}$$

$$A_2 = \frac{A \left[(W_L - W_{E1}) \cdot (W_L + W_D) \right]}{(W_L + W_D)^2 + (W_L - W_{E1}) \cdot (W_L + W_D) + (W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D)}$$

$$\therefore A_1 = \frac{A (W_L + W_D)^2}{\left[(W_L + W_D)^2 + (W_L - W_{E1}) \cdot (W_L + W_D) + (W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D) \right]}$$

$$A_3 = \frac{A \left[(W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D) \right]}{\left[(W_L + W_D)^2 + (W_L - W_{E1}) \cdot (W_L + W_D) + (W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D) \right]}$$

$$\therefore A_1 : A_2 : A_3 = (W_L + W_D)^2 : \left[(W_L - W_{E1}) \cdot (W_L + W_D) \right] : \left[(W_L - W_{E1})^2 + (W_{E1} - W_{E3}) \cdot (W_L + W_D) \right]$$

Substitute value of W_L = 25 mm/day

W_D = 1.0 mm/day

first week crop coefficient = 0.99

third " " " = 0.99

and potential evapotranspiration = 5.89 mm/day

therefore $A_1 : A_2 : A_3 = 43.8 : 32.3 : 23.9$

If let the area to be irrigated is 1,000 rai and delivery efficiency is 85 %

$$\text{flowrate} = \frac{438}{0.85} \times (25 + 1.0) \times \frac{1}{1{,}000} \times \frac{1}{24 \times 3{,}600} \times 1{,}600$$

$$= 0.248 \text{ m}^3/\text{sec}$$

L. Potential evapotranspiration and crop coefficient for rice in Thailand (Translation)

Original report (Thai version) : by Mr.Drek Tongaram

1. Preface

Consumptive use of water especially rice consumptive use is an important basis in deterimining irrigation projects, quantity and frequency of watering planting system designing and also including investments which will help in developing the water reservoir for agriculture.

2. What is the consumptive use or evapotranspiration ?

Generally it is the total of water losses from the growing area to the atmosphere in the form of water vapor (Figure 1)

2.1 The evaporation of water from plant surface directly into the atmosphere, or into intercellular spaces and then diffusion through the stomates to the atmosphere is calles transpiration.

2.2 Water evaporated from the soil, or exterior portions of the plants where water may have accumulated from irrigation, rainfall, dew or exudation from the exterior of the plant is called evaporation.

3. Measurement of consumptive use or evapotranspiration.

3.1 Direct methods which the results can be used directly :

Each method also has advantage and disadvantage. Selecting the methods is depended on types of plant, expenses and etc. Methods that are generally used in irrigation are :

3.1.1 measuring directly by using lysimeter
3.1.2 studying from soil moisture content
3.1.3 studying from experimental fields

3.2 Calculation for potential evapotranspiration by the use of empirical formulas based on climatological data :

The calculation can be done in many ways - simple or complex depends on each formula. The water requirement is obtained by multiplying potential evaporation by crop coefficient.

4. Studying trends

Although the use of lysimeter is very accuracy in determining the crop water requirement, its result can not be used in all areas which the environment or climatic condition is differnt from where it is set, therefore the estimated crop evapotranspiration, obtained by potential evapotranspiration times crop coefficient, is used.

There were many methods for the estimation for potential evapotranspiration,thus the study was to obtain the methods that were suitable for this country. The experiments were set in 49 places covered all regions of Thailand. If provided water was enough for growing rice, it should be enough for other plants since rice needed more water than others. Therefore, the study was also on the rice coefficient.

5. What is potential evapotranspiration ?

Potentaial evapotranspiration is the water losses from growing areas assuming that the soil has enough moisture for the requirement of plant and the growing areas are large enough that the transpiration and evaporation will not be affected by other factors eg. hot dry wind and etc.

6. The purposes of this study were :

6.1 To determine the methods that gave the most reliable potential evapotranspiration obtained by comparing with the direct measurement of lysimeter.

The methods were :

6.1.1 Penman method (Combination equation)
6.1.2 Christiansen and Hargreaves Method
6.1.3 E-pan Method
6.1.4 Makkink Method
6.1.5 Blaney Criddle method
6.1.6 Thornthwaite method

The basic determination was that the method that gave the closest value of potential evapotranspiration to evapotranspiration obtained from lysimeter was the best method.

6.2 To obtain the optimal value of rice coefficient for the estimation for water requirement for rice.

The basic determination was also the same as the above that the method that gave the closest crop coefficient to that of obtained from lysimeter was the most reliable method.

7. Summary on the study of each method

The studies were conducted in 2 periods. The first period was from wet season 1978 to dry season 1979 and the second period was from wet season 1980 to dry season 1980. The result was that the Penman method was the best for the climatic of Thailand. (see Main Report) The reason was that the Penman method used all climatic information that related to transpiration and evaporation.

Therefore it would give the accuracy value and also it could be used in all regions of Thailand.

Other formulas gave less accuracy value because they used less data that related to evapotranspiration than Penman method.

Makkink method used solar radiation as Penman's but did not use vapor pressure and wind speed.

E-pan or evaporation from pan was the sum of solar radiation,wind speed, temperature and relative humidily. The estimation for water requirement was quite error because the evaporation pan was often set in the different places from where the growing areas were.

Christiansen and Hargreaves method also used the evaporation from pan as the main data, thus the result was the same as that of E-pan method.

Thornwaite and Blaney Criddle methods used only temperature as the main data, thus the accuracy was less than that of Penman method.

Blaney Criddle method was very simple and easy to use since it used only mean monthly temperature but it had weak point as follows :

7.1 The temperature of the atmosphere was not exactly the amount of heat energy required for evaporation and transpiration. The real energy was solar radiation which was not proportionate to the temperature of the atmosphere. For example mean temperatures in November and March of the Netherlands were 5.4 and 5°c which the numbers were very close but the solar radiation or water requirement for plant was different almost 4 times.

7.2 The temperative especially after winter was increased but slower than solar radiation which the earth recieved, Therefore water requirement for plant obtained from this formula during that period would be lower than the actual requirement of plant.

7.3 According to Blaney Criddle, there were no evaporation and transpiration when the temperature was equal or less than 0°c That was not true because the temperature that used was the mean monthly temperature which could be higher or lower than 0°c in that month.

7.4 Blaney Criddle method did not include the wind speed including the effect of hot-dry wind which affected directly to evaporation and transpiration.

However, the areas which had no information other than temperature, Blaney Criddle method could be roughly used in estimating the water requirement for plant.

Although Blaney Criddle method had weak points, it was widely used because it used crop coefficient, K which depended on types, ages, heights, and also including the density of plants. If the measurement of water requirement for plant was accuracy, the calculated crop coefficient would be correct and optimum for that climatic area.

8. The uses of the studied methods

The experiment showed that the estimation for potential evapotranspiration by Penman method was the best and optimum for all regions of Thailand. Since Penman method needed a lot of information and the calculation was complicated. The potential evapotranspiration was obtained only in 25 period (during 1951-1975) and covered with 49 statious in all regions of Thailand.

Potential evapotranspiration could be used to estimate the water requirement for all plant which obtained by multiplying potential-evapotranspiration by cropcoefficient of that plant.

The results from this study are shown as follows :

8.1 Appendices A : Monthly potential evapotranspiration in mm/month and mm/day.

8.2 Appendices B : Monthly potential evapotranspiration of 49 stations in mm/day.

8.3 Appendices C : Elevation of potential evapotranspiration in mm/month.

8.4 Appendices D : Potential evapotranspiration value in mm/day

9. Summary of estimation of rice coefficient.

The averages obtained from the first phase (wet season 1978 - dry season 1979) and second phase (wet season 1979- dry season 1980-wet season 1980) by comparing the crop evapotranspiration and potential evapotranspiration were shown in mean monthly values and average values for calculation for potential evapotranspiration by Penman method (Appendices E).

Month	Crop coefficient		
	Phase 1	Phase 2	Average
1	1.04	0.97	1.00
2	1.12	1.20	1.16
3	1.27	1.48	1.37
4	1.18	1.36	1.27
Average	1.15	1.25	1.20

The table shows that the crop coefficients of the first phase are quite good for practical use and also the first and second months of the second phase. The third and forth months of the second phase, the values are quite high thus causing higher average values of crop coefficient. The reasons for that are as follows.

9.1 The effect of heat from solar energy around the growing area in the abnormal seasons especially in dry season, the temperature in the area of some experimental stations was lower than that of natural condition therefore the rate of water requirement for rice in the experimental field was high and also higher than that obtained from potential evapotranspiration, thus causing higher crop coefficient.

9.2 The water losses by evaporation and transpiration were still high when the irrigated water was drained from the field around the experimental field during the delay in ripening of rice.

However, the crop coefficients from the first and second phases and the averages of both phases were in the working range because they were from the results of actual but different in conditions.

10. <u>Suggestion of crop coefficient of RD rice varieties.</u>

Rice coefficient was the basic information for irrigation because designing, planning and operating the irrigation system depended on water requirement of rice especially for RD rice varieties which could grow all year round since they were not sensitive to light. There were no researches in this area and normally the statistics from foreign countries were used to estimate the water requirement for rice. And the values were not yet perfectly fit the actual condition. The result was the losses of water especially in the area of the efficiency of using water was low.

In order to solve the problem, the author who was responsible for this research had conducted the experiment on rice coefficient that would be suitable for the climatic of this country especially potential evapotranspiration formulas (shown in Appendice A-D). The experiments were covered all over the country with 49 stations. For examination and the uses the author developes 3 sets of crop coefficients; namely Direks 1,2,3

Month	Crop coefficient for RD. - Rice		
	Direk 1	Direk 2	Direk 3
1	1.04	0.97	1.00
2	1.12	1.20	1.16
3	1.27	1.48	1.37
4	1.18	1.36	1.27
Average	1.15	1.25	1.20

<u>Notice</u> : To obtain the crop coefficient value for the fifth month, the author suggests that the value of 0.98 should be added (this number was obtained from the study during wet season 1978 to dry season 1979). The crop coefficient values are shown only in 4 months because normally the use of water in the ricefield is about 80-90 days while about 25-30 days for transplanting and the rest are the draining period before harvesting (see more detail in Executive Summary)

For Direk 1 and 2 were obtained from 2 experiments (see main report) and Direk 3 was the average of Direks 1 and 2.

The arrangement according to the importance to the users were Direks 1,3 and 2 respectively.

Direks 1 and 3 were optimum for designing project planning and etc. while Direk 2 was for operation in the case of higher climatic condition.

In order to use the crop coefficients effectively the rice coefficients obtained from both experiment were shown in Appendices E.

The importance in obtaining the water requirement for rice was that the potential evapotranspiration had to come from the Penman method. If using potential evaporation from other methods eg. Blaney Criddle, E-pan, Thornthwaite, Makkink and Christiansen and Hargreaves the result would be lower or higher than the actual values depending on the nature of the methods. Other methods could also used the given crop coefficient but their coefficient had to develop according to the climatic of this country.

11. Summary on water requirement for rice by the use of lysimeter and the usages.

The measurement of water requirement by using lysimeter was reliable and could be used directly in the rice field. The 2 experiments area were to obtain the estimation of water requirement in each area or provinces which having the same or related climatic conditions. The results are shown in Appendices G which the users can follow as :

11.1 The result from Mae Tang station can be used in the North region.

11.2 The result from Sam Chuk station can be used in the lower North and Central regions.

11.3 The result from Huai Ban Yang station can be used in the Northeastern region.

11.4 The result from Mae Klong Yai station can be used in the West region.

11.5 The result from Petburi station can be used in some parts of Central, West and upper part of South region.

The area in the different climatic conditions or environment (although in the same region), the potential evapotranspiration had to come from that specific area in order to obtain the actual values.

12. Summary and Suggestion

12.1 Potential evapotranspiration or water requirement for plant obtained from Penman's method was the best for the climatic of Thailand.

The potential evapotranspiration for the important areas were calculated 49 stations located all over the region of Thailand were used. The water requirement for plant was obtained from potentail evapotranspiration of the specific area timed coefficient of that specific crop.

12.2 The potential evapotranspiration values obtained from the 6 methods were compared with those of lysimeter and the results showed taht Penman method was the best. And from the results, the 3 sets of crop coefficient were estâblished fòr the convenience of the users.

13 Summary

Potential Evapotranspiration and Crop Coefficient for Rice in Thailand.

(Users summary)

This report is prepared in the connection with a report entitle "A Comparision of Rice Evapotranspiration and Effective Rainfall in the Ricefield", which concluded, from the result of a consumptive use or rice evapotranspiration experimental data observed in 1978-1981, the recommended method-Penman (Combination equations) in determining the potential evapotranspiration as well as crop coefficient for rice. In this connection, the monthly potential evapotranspiration of 49 staions in various part of Thailand, by using Penman's formula (Combination equations), based on an average of 15 years of climatological as well as the crop coefficient for RD-rice were established for planning and operation of an irrigation purposes.

This determination is first in its kind of information ever been made available for either planning or operation project in Thaialnd.

14. Monthly Potential evapotranspiration (mm/month)

(Unit:millimeter)

No.	Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	Chieng Rai	93	125	151	169	158	143	135	124	128	122	105	91
2	Mae Hong Sorn	102	134	166	185	161	139	131	123	125	123	112	97
3	Chiengmai	104	134	164	179	160	144	135	122	124	123	110	96
4	Mae Sa Rieng	108	139	173	191	166	135	127	120	125	127	117	103
5	Lam Pang	109	139	167	184	167	151	144	132	130	125	113	100
6	Nan	102	133	162	177	158	144	135	124	126	126	112	97
7	Phrae	108	137	170	188	168	145	142	130	128	125	115	103
8	Uttaradit	114	140	165	180	160	140	133	124	128	132	123	109
9	Tak	115	147	182	198	167	150	144	134	128	121	112	103
10	Phitsanulok	113	138	165	175	159	143	136	126	128	129	121	108
11	Mae Sot	117	146	177	190	163	135	128	118	127	130	123	110
12	Petchaburi	118	143	176	180	160	140	132	122	123	131	124	112
13	Phummipol Dam	116	153	186	197	166	148	143	141	130	125	116	106
14	Loei	119	146	172	183	167	155	153	143	139	139	124	109
15	Udon Thani	112	137	165	174	158	144	140	128	131	134	121	107
16	Nakhon Phanom	113	133	157	166	155	134	132	122	127	132	121	107
17	Sakhon Nakorn	114	138	163	173	154	143	141	129	132	135	122	108
18	Mukdahan	119	140	167	172	156	141	136	128	135	135	127	114
19	Khon Kaen	117	143	168	177	162	148	147	133	132	131	126	113
20	Roi Et	119	140	165	171	159	147	143	130	129	132	126	114
21	Ubon Ratchathani	125	145	166	168	155	140	140	129	129	134	132	120
22	Surin	119	139	162	162	150	137	135	125	124	126	119	110

No.	Station	(Month) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept	Oct	Nov.	Dec
23	Nakhon-Ratchasima	120	143	163	168	158	151	146	134	132	127	122	112
24	Sap Muang	113	131	147	153	145	142	137	125	125	119	112	105
25	Chaiyaphum	125	150	172	179	172	150	144	133	130	135	130	119
26	Nakhon Sawan	122	149	179	187	167	152	144	134	127	126	121	113
27	Lop Buri	131	152	177	179	161	148	141	132	131	133	131	128
28	Suphanburi	129	147	174	182	168	155	149	142	134	132	128	121
29	Phrachin Buri	132	147	161	162	152	136	132	158	127	131	134	128
30	Kanchanaburi	125	151	177	182	163	148	144	135	133	127	121	116
31	Don Muang	130	148	169	170	158	150	145	133	132	131	126	119
32	Bangkok Metropolis	120	136	153	156	144	136	132	126	123	120	119	113
33	Aranyaprathet	126	148	166	166	158	144	137	129	131	130	126	117
34	Chon Buri	131	149	168	171	153	149	143	136	131	131	131	130
35	Sattahip	140	156	171	170	152	158	151	146	139	133	137	139
36	Chanthaburi	128	134	139	146	132	123	121	115	117	123	128	127
37	Khlong Yai	124	130	137	137	129	120	119	112	116	121	122	123
38	Koh Sichang	133	150	166	171	156	152	146	139	134	137	135	132
39	Hua Hin	127	145	165	167	152	146	139	132	132	127	125	123
40	Pracheub Khirikan	125	141	159	164	154	145	142	137	140	129	128	127
41	Chumphon	117	133	152	154	139	130	127	150	128	121	113	111
42	Surat Thani	120	143	158	155	142	136	135	131	114	123	110	107
43	Nakhon Si Thamma-rat	116	137	157	153	143	140	142	135	101	124	110	107
44	Songkhla	103	144	153	147	135	133	135	133	79	124	113	116
45	Narathiwat	121	136	151	154	138	135	133	131	57	127	115	110
46	Ranong	130	145	158	153	130	118	117	113	109	115	108	120

No.	Station	(Month) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
47	Phuket	143	159	167	155	132	132	133	132	82	126	124	132
48	Phuket Airport	134	150	157	148	137	127	128	125	88	120	120	123
49	Trang	140	158	166	155	131	121	128	123	72	122	117	123

15. Daily Potential evapotranspiration (mm/day)

Unit : millimeter/day

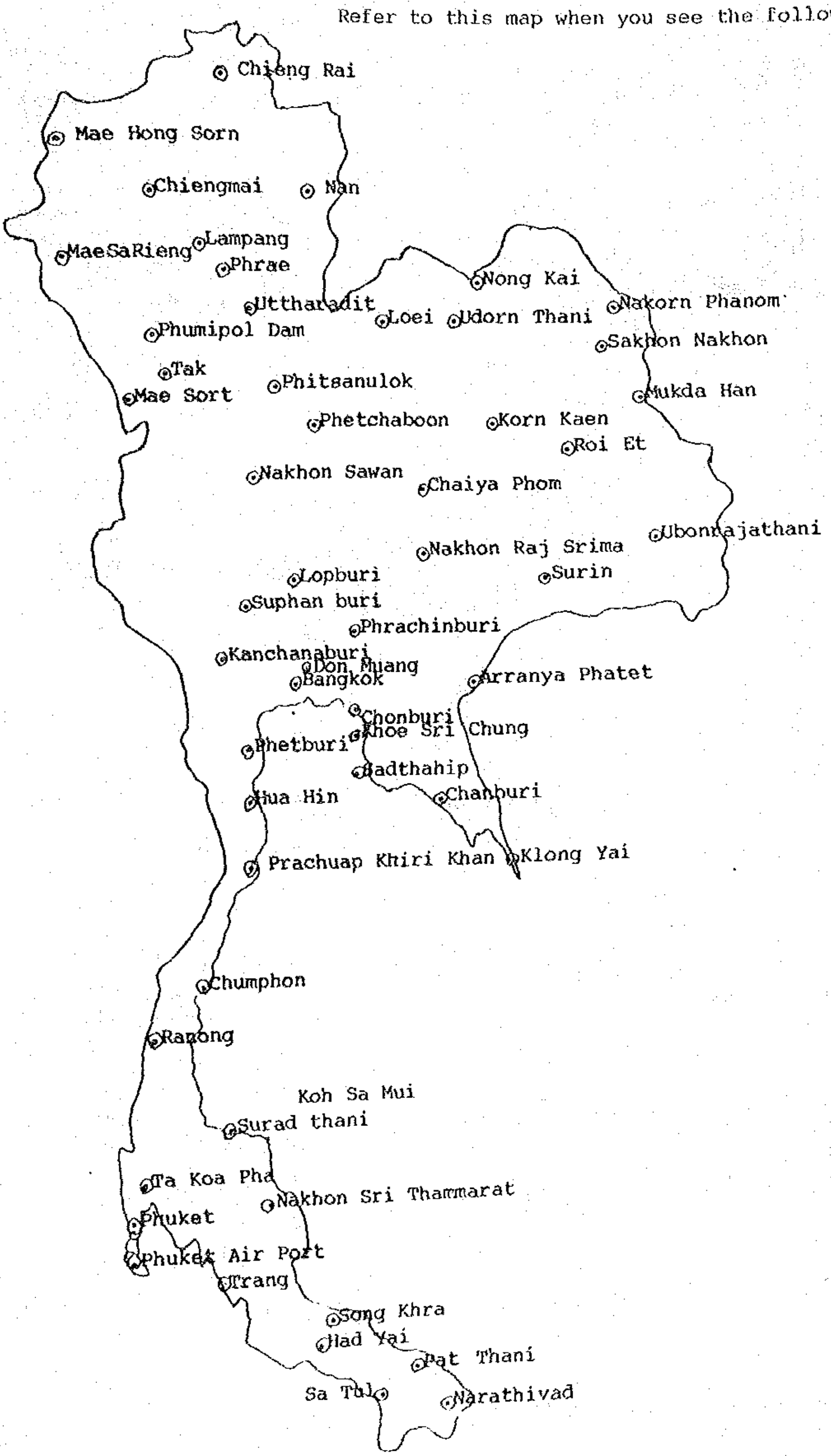
No.	Station	(Month)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	Chieng Rai	2.99	4.46	4.88	5.63	5.08	4.75	4.35	4.01	4.27	3.92	3.49	2.92
2	Mae Hong Sorn	3.30	4.77	5.35	6.16	5.20	4.62	4.23	3.95	4.15	3.95	3.73	3.12
3	Chiengmai	3.34	4.79	5.29	5.98	5.16	4.79	4.34	3.93	4.13	3.95	3.65	3.11
4	Mae Sa Rieng	3.46	4.95	5.75	6.36	5.34	4.49	4.08	3.85	4.17	4.11	3.90	3.32
5	Lam Pang	3.50	4.95	5.37	6.14	5.39	5.04	4.63	4.26	4.33	4.03	3.76	3.22
6	Nan	3.28	4.74	5.22	5.88	5.10	4.78	4.37	4.00	4.20	4.05	3.71	3.12
7	Phrae	3.48	4.88	5.48	6.26	5.42	4.82	4.58	4.18	4.26	4.03	3.84	3.31
8	Uttaradit	3.67	4.99	5.31	6.01	5.17	4.66	4.30	3.99	4.26	4.26	4.09	3.52
9	Tak	3.71	5.26	5.87	6.58	5.37	5.00	4.64	4.33	4.26	3.90	3.73	3.33
10	Phitsanulok	3.63	4.91	5.31	5.83	5.13	4.77	4.38	4.05	4.27	4.16	4.02	3.48
11	Mae Sot	3.76	5.20	5.70	6.31	5.26	4.51	4.12	3.80	4.22	4.20	4.10	3.56
12	Phetchaburi	3.81	5.11	5.67	6.00	5.15	4.67	4.25	3.93	4.09	4.22	4.13	3.60
13	Phumipol Dam	3.75	5.46	5.99	6.57	5.36	4.93	4.60	4.53	4.33	4.04	3.86	3.40
14	Loei	3.82	5.20	5.53	6.09	5.38	5.16	4.93	4.59	4.64	4.49	4.13	3.53
15	Udon Thani	3.61	4.90	5.32	5.79	5.08	4.81	4.50	4.13	4.37	4.31	4.04	3.43
16	Nakhon Phanom	3.66	4.74	5.05	5.53	4.98	4.47	4.24	3.92	4.24	4.25	4.02	3.46
17	Sakhon Nakorn	3.68	4.93	5.26	5.75	4.97	4.76	4.55	4.16	4.40	4.35	4.08	3.48
18	Mukdahan	3.82	5.00	5.37	5.74	5.02	4.71	4.37	4.13	4.50	4.36	4.24	3.67
19	Khon Kaen	3.78	5.10	5.41	5.90	5.22	4.93	4.72	4.29	4.39	4.22	4.19	3.63
20	Roi-Et	3.83	5.00	5.32	5.69	5.11	4.90	4.62	4.18	4.30	4.26	4.19	3.69
21	Ubon Ratchathani	4.02	5.16	5.35	5.59	5.01	4.66	4.52	4.15	4.30	4.32	4.40	3.87
22	Surin	3.85	4.96	5.22	5.39	4.83	4.56	4.36	4.04	4.13	4.06	3.97	3.56

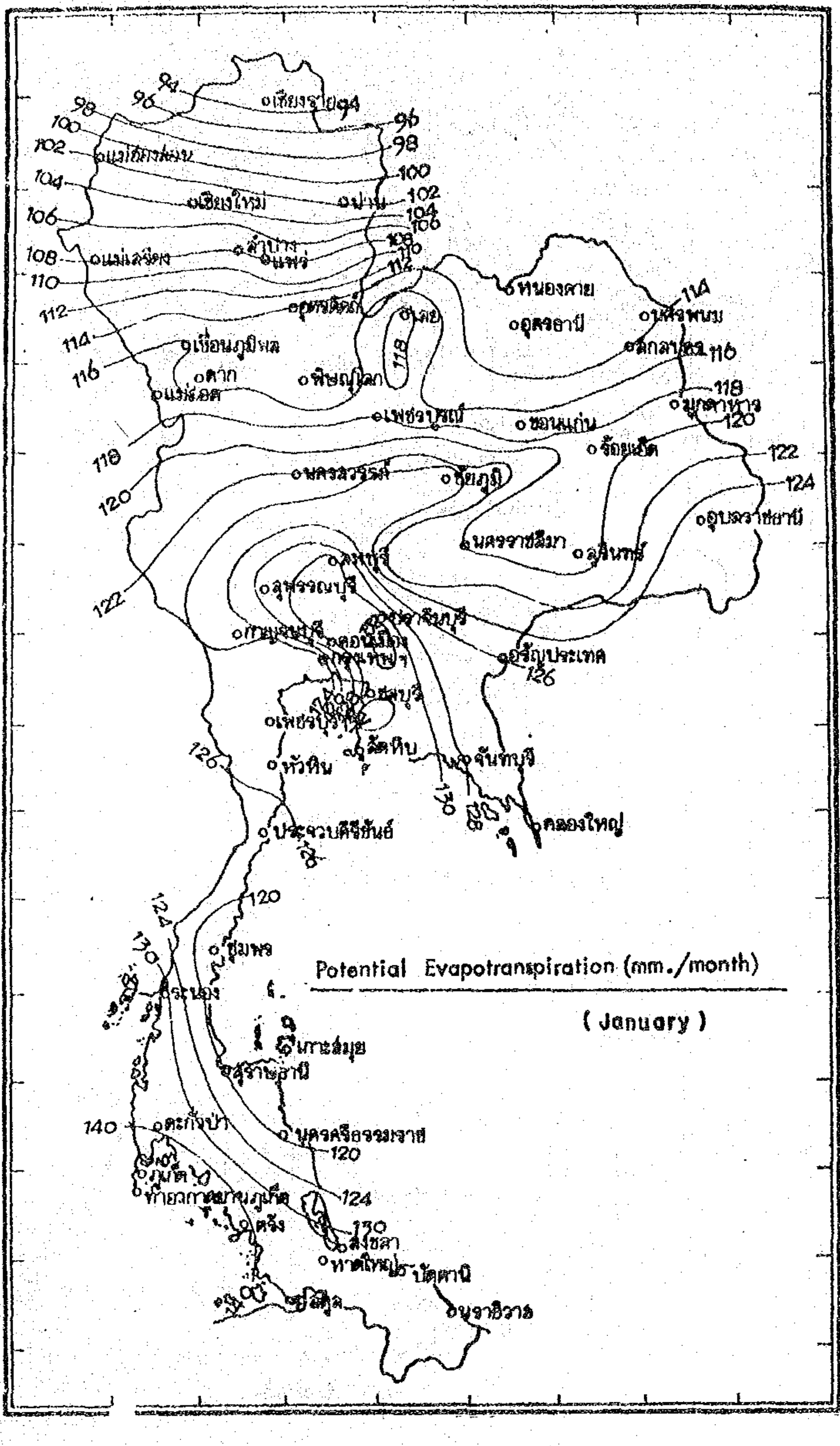
No.	Station	(Month)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
23	Nakhon Ratchasima	3.86	5.12	5.25	5.61	5.10	5.03	4.71	4.32	4.40	4.10	4.05	3.62
24	Sap Muang	3.64	4.69	4.74	5.09	4.68	4.72	4.41	4.03	4.17	3.84	3.72	3.37
25	Chaiyaphum	4.04	5.34	5.55	5.97	5.54	4.99	4.63	4.30	4.33	4.34	4.32	3.84
26	Nakhon Sawan	3.95	5.31	5.78	6.22	5.37	5.07	4.63	4.31	4.23	4.06	4.04	3.65
27	Lop Buri	4.23	5.42	5.70	5.95	5.20	4.94	4.56	4.25	4.38	4.29	4.35	4.12
28	Suphan Buri	4.14	5.25	5.60	6.08	5.41	5.16	4.81	4.57	4.47	4.26	4,25	3.91
29	Prachin Buri	4.27	5.26	5.19	5.39	4.90	4.52	4.25	5.08	4.23	4.23	4.47	4.11
30	Kanchanaburi	4.02	5.40	5.69	6.07	5.27	4.92	4.64	4.36	4.43	4.09	4.04	3.75
31	Don Muang	4.20	5.29	5.43	5.65	5.10	4.99	4.67	4.29	4.41	4.22	4.21	3.82
32	Bangkok Metropolis	3.85	4.85	4.92	5.19	4.65	4.57	4.27	4.06	4.09	3.86	3.95	3.63
33	Aranyaprathet	4.07	5.27	5.37	5.53	5.08	4.80	4.43	4.16	4.38	4.19	4.18	3.77
34	Chon Buri	4.23	5.30	5.40	5.69	4.94	4.97	4.62	4.38	4.37	4.23	4.35	4.18
35	Sattahip	4.52	5.55	5.52	5.68	4.88	5.25	4.88	4.69	4.61	4.29	4.57	4.47
36	Chanthaburi	4.13	4.79	4.49	4.85	4.27	4.09	3.90	3.72	3.90	3.98	4.26	4.08
37	Klong Yai	3.99	4.63	4.42	4.56	4.16	4.00	3.84	3.59	3.88	3.90	4.07	3.97
38	Koh Sichang	4.30	5.34	5.36	5.69	5.01	5.06	4.70	4.47	4.45	4.42	4.49	4.24
39	Hua Hin	4.09	5.16	5.31	5.58	4.90	4.85	4.47	4.27	4.39	4.09	4.16	3.97
40	Pracheup Kirikan	4.03	5.03	5.13	5.47	4.96	4.83	4.58	4.41	4.65	4.17	4.27	4.10
41	Chumphon	3.77	4.75	4.89	5.13	4.47	4.33	4.10	4.83	4.25	3.91	3.77	3.57
42	Surat Thani	3.88	5.10	5.11	5.16	4.57	4.53	4.34	4.22	3.79	3.95	3.67	3.45
43	Nakhon Sri Tham marat	3.74	4.88	5.06	5.08	4.60	4.67	4.56	4.36	3.35	3.99	3.65	3.45
44	Songkhla	4.18	5.15	4.94	4.90	4.35	4.42	4.36	4.30	2.64	4.00	3.77	3.73
45	Narathiwat	3.89	4.86	4.88	5.14	4.46	4.49	4.36	4.23	1.89	4.08	3.82	3.56

No.	Station	(Month)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
46	Ranong	4.18	5.18	5.10	5.09	4.17	3.92	3.78	3.65	3.63	3.70	3.59	3.86
47	Phuket	4.61	5.67	5.38	5.17	4.26	4.40	4.27	4.27	2.72	4.06	4.13	4.26
48	Phuket Airport	4.32	5.34	5.07	4.93	4.40	4.24	4.12	4.03	2.92	3.88	4.00	3.95
49	Trang	4.50	5.64	5.35	5.16	4.23	4.03	4.12	3.97	2.41	3.92	3.89	3.96

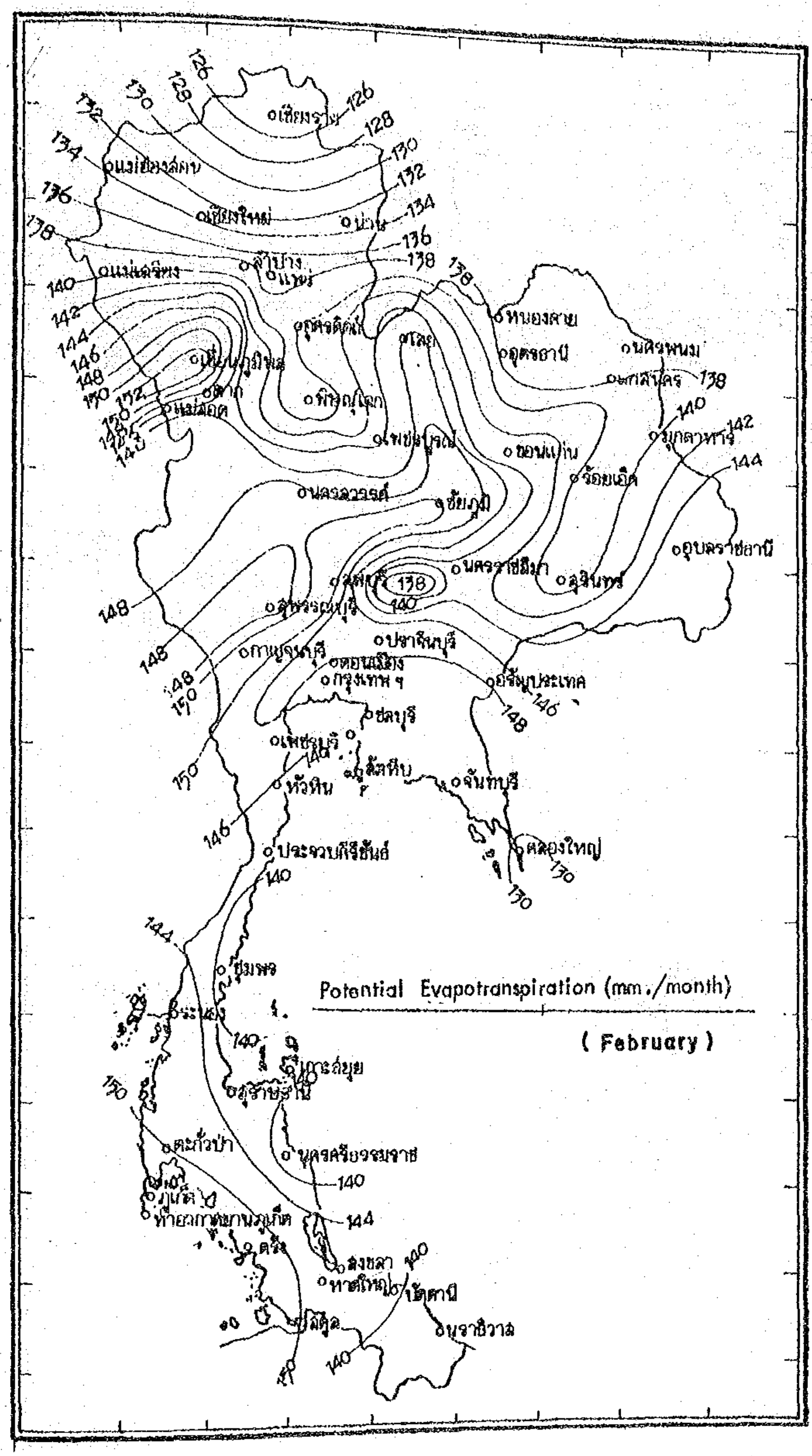
16. Potential evapotranspiration elevation, mm/month

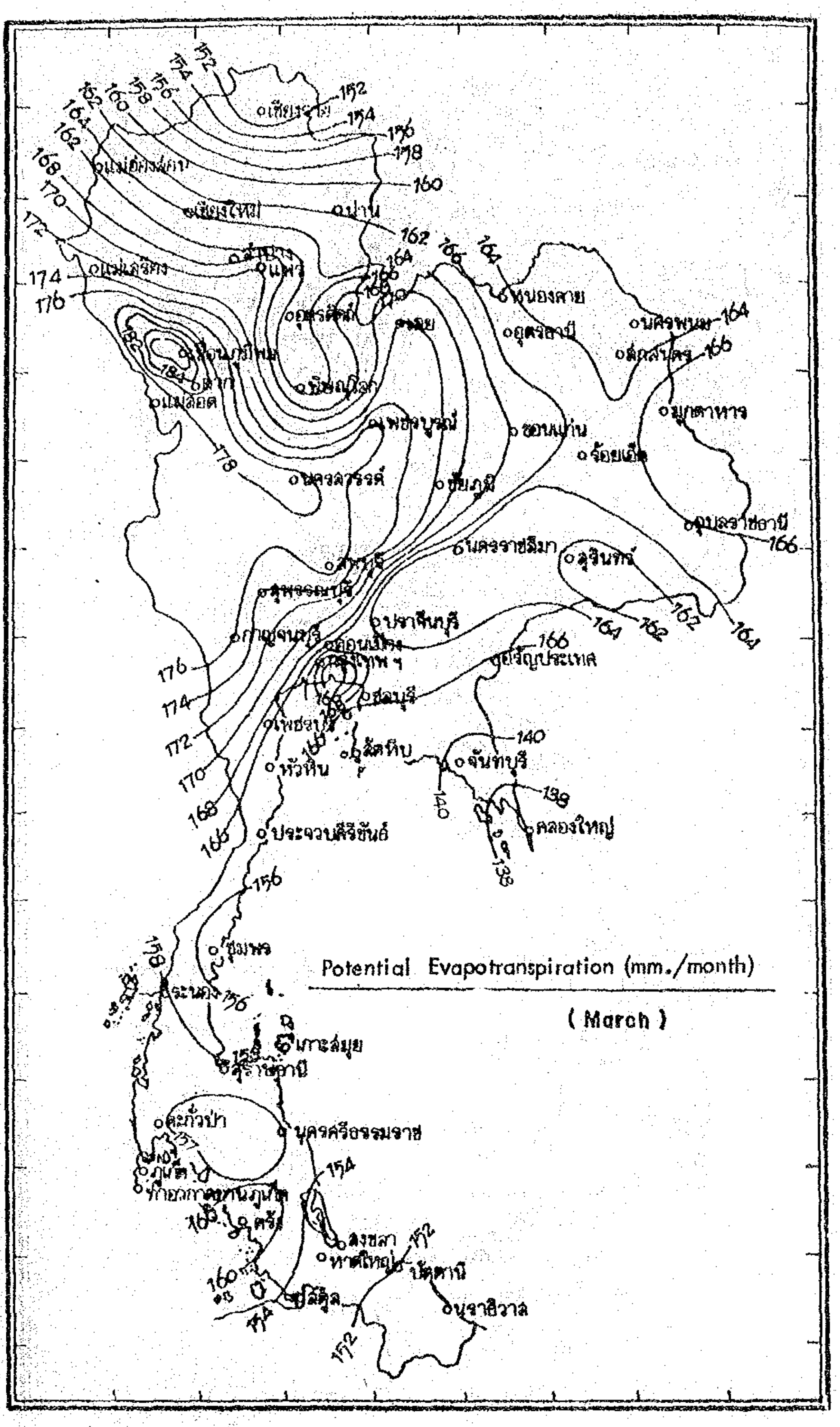
Refer to this map when you see the followings

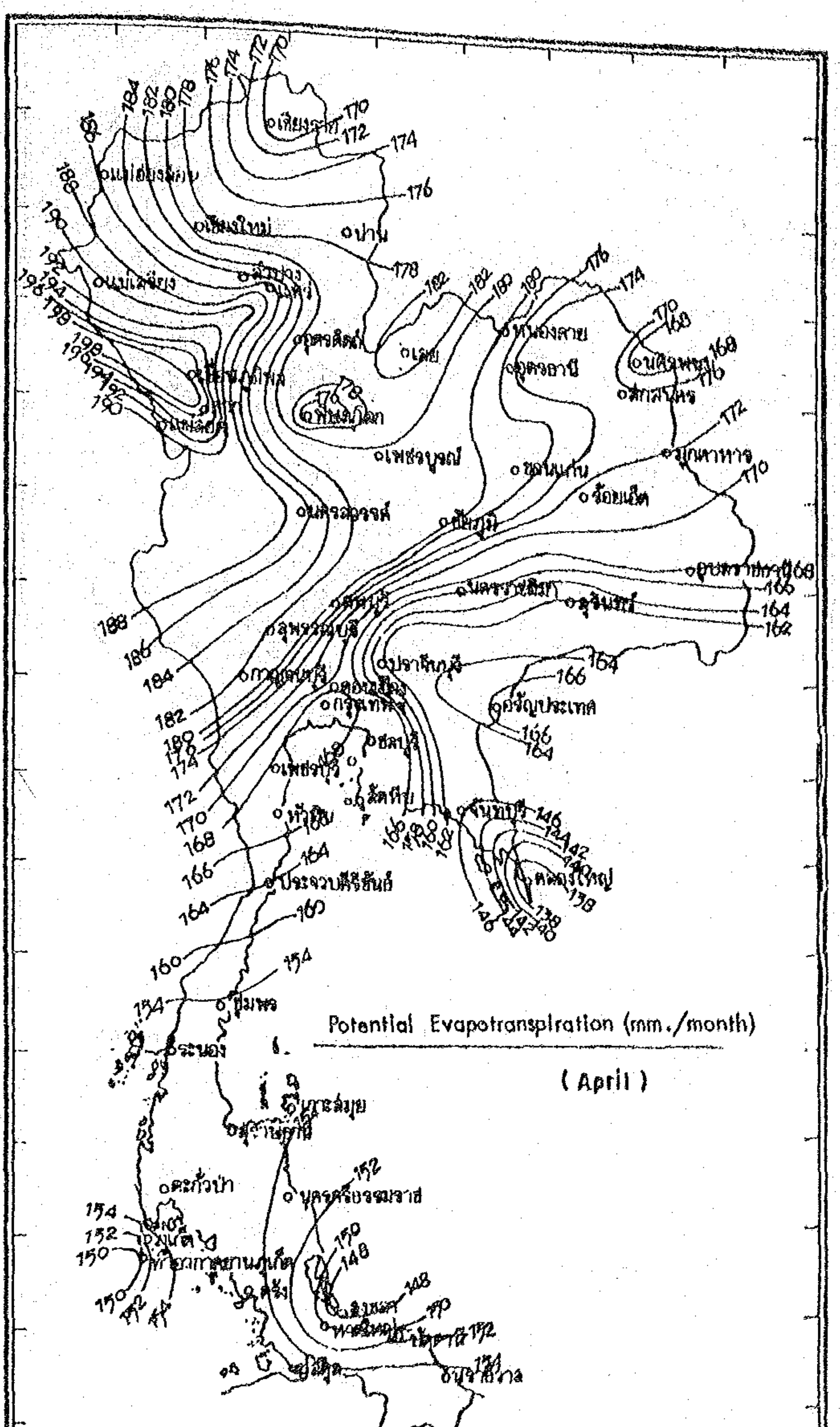


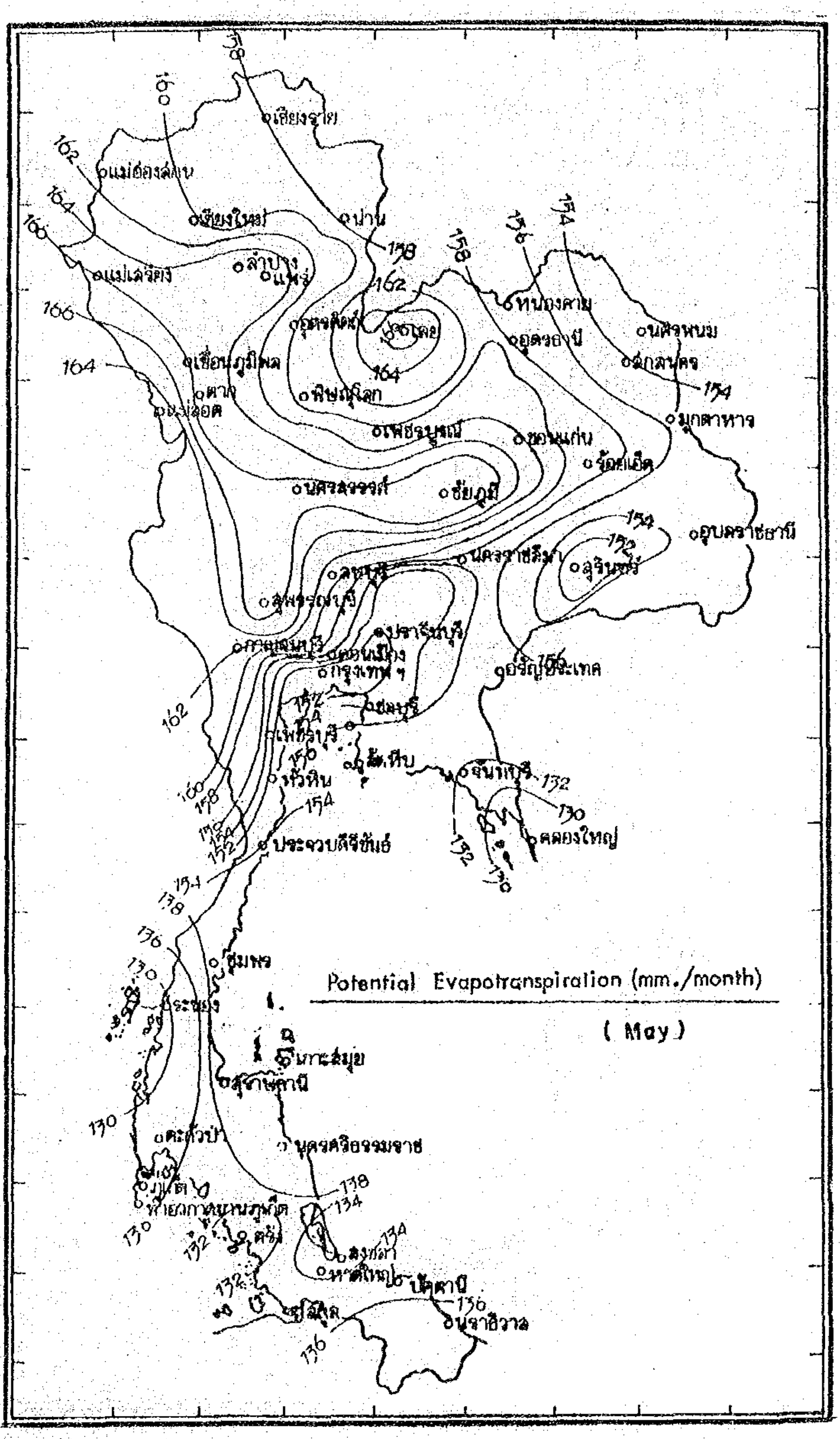


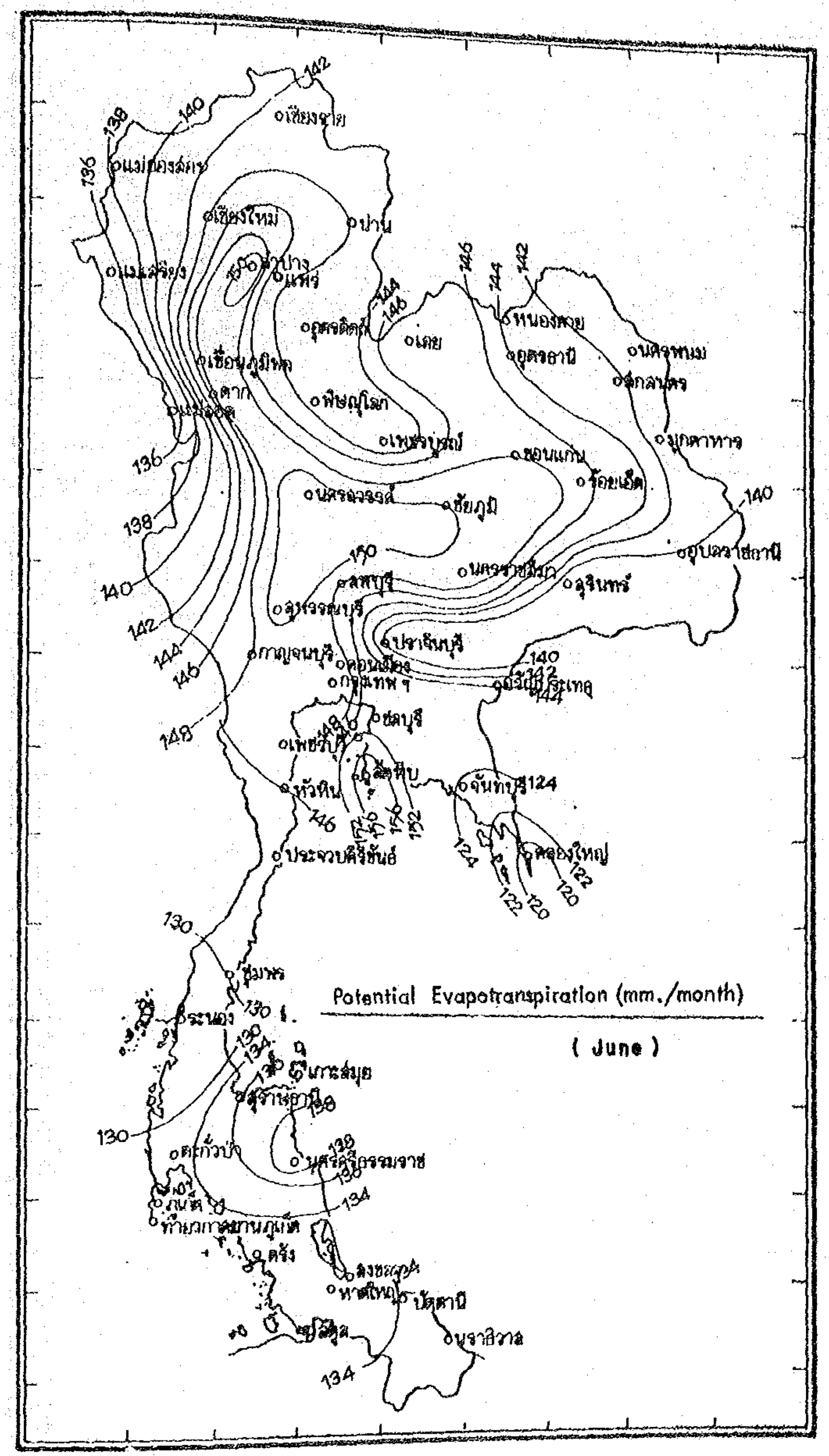
Potential Evapotranspiration (mm./month)
(January)
เชียงราย
เชียงใหม่
น่าน
แพร่
ลำปาง
หนองคาย
อุดรธานี
เลย
พิษณุโลก
ตาก
เพชรบูรณ์
ขอนแก่น
ร้อยเอ็ด
นครสวรรค์
ชัยภูมิ
นครราชสีมา
สุรินทร์
อุบลราชธานี
สุพรรณบุรี
กาญจนบุรี
อรัญประเทศ
ชลบุรี
สัตหีบ
จันทบุรี
คลองใหญ่
หัวหิน
ประจวบคีรีขันธ์
ชุมพร
ระนอง
เกาะสมุย
สุราษฎร์ธานี
ตะกั่วป่า
นครศรีธรรมราช
ภูเก็ต
ตรัง
สงขลา
หาดใหญ่
ปัตตานี
สตูล
นราธิวาส
94
96
98
100
102
104
106
108
110
112
114
116
118
120
122
124
126
130
140

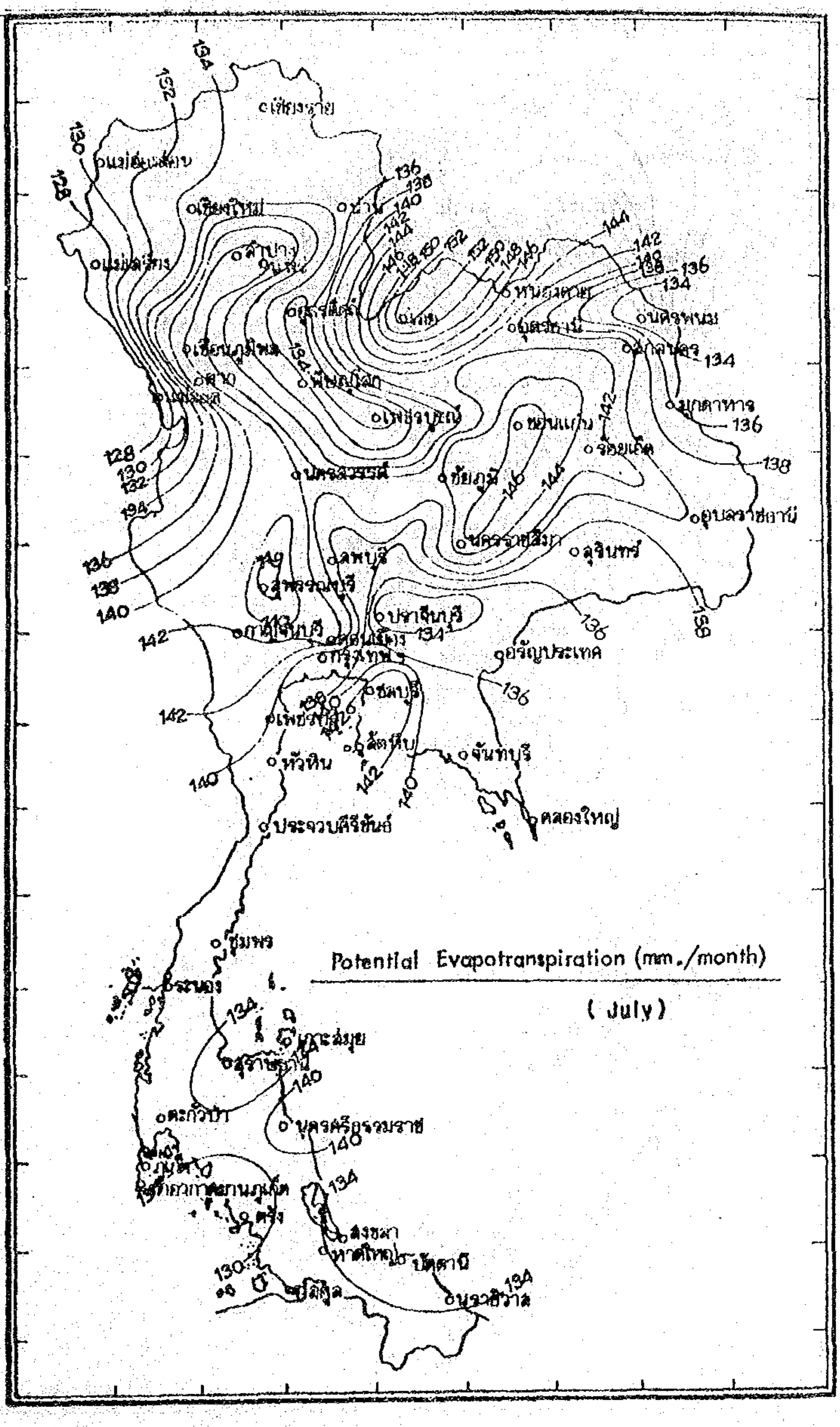

Potential Evapotranspiration (mm./month)
(February)
เชียงราย
เชียงใหม่
น่าน
ลำปาง
แพร่
หนองคาย
อุดรธานี
ขอนแก่น
ร้อยเอ็ด
ชัยภูมิ
นครราชสีมา
สุรินทร์
อุบลราชธานี
ปราจีนบุรี
ชลบุรี
จันทบุรี
คลองใหญ่
หัวหิน
ประจวบคีรีขันธ์
ชุมพร
ตะกั่วป่า
สงขลา
นราธิวาส


Potential Evapotranspiration (mm./month)
(March)


Potential Evapotranspiration (mm./month)
(April)

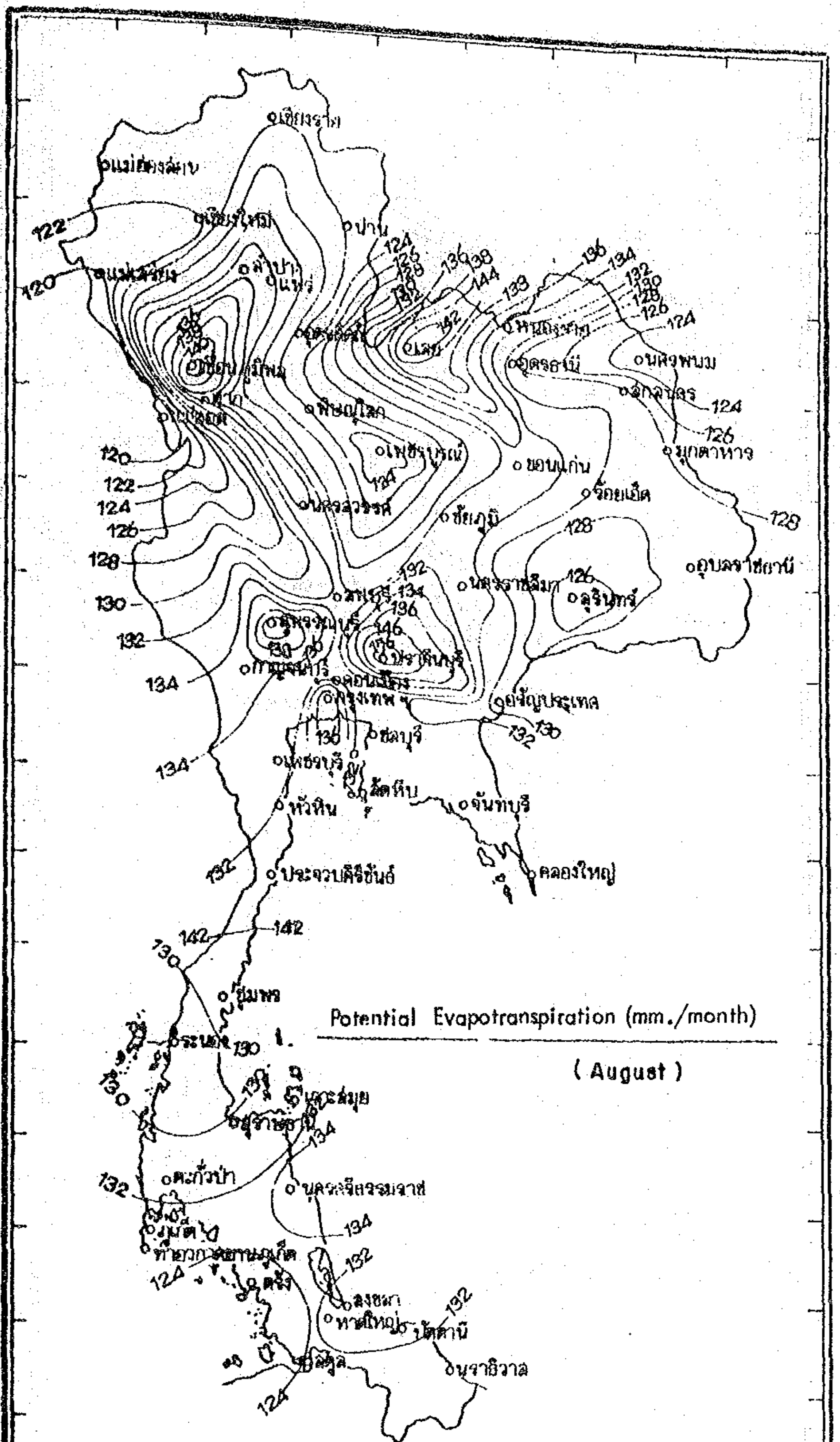

Potential Evapotranspiration (mm./month)
(May)

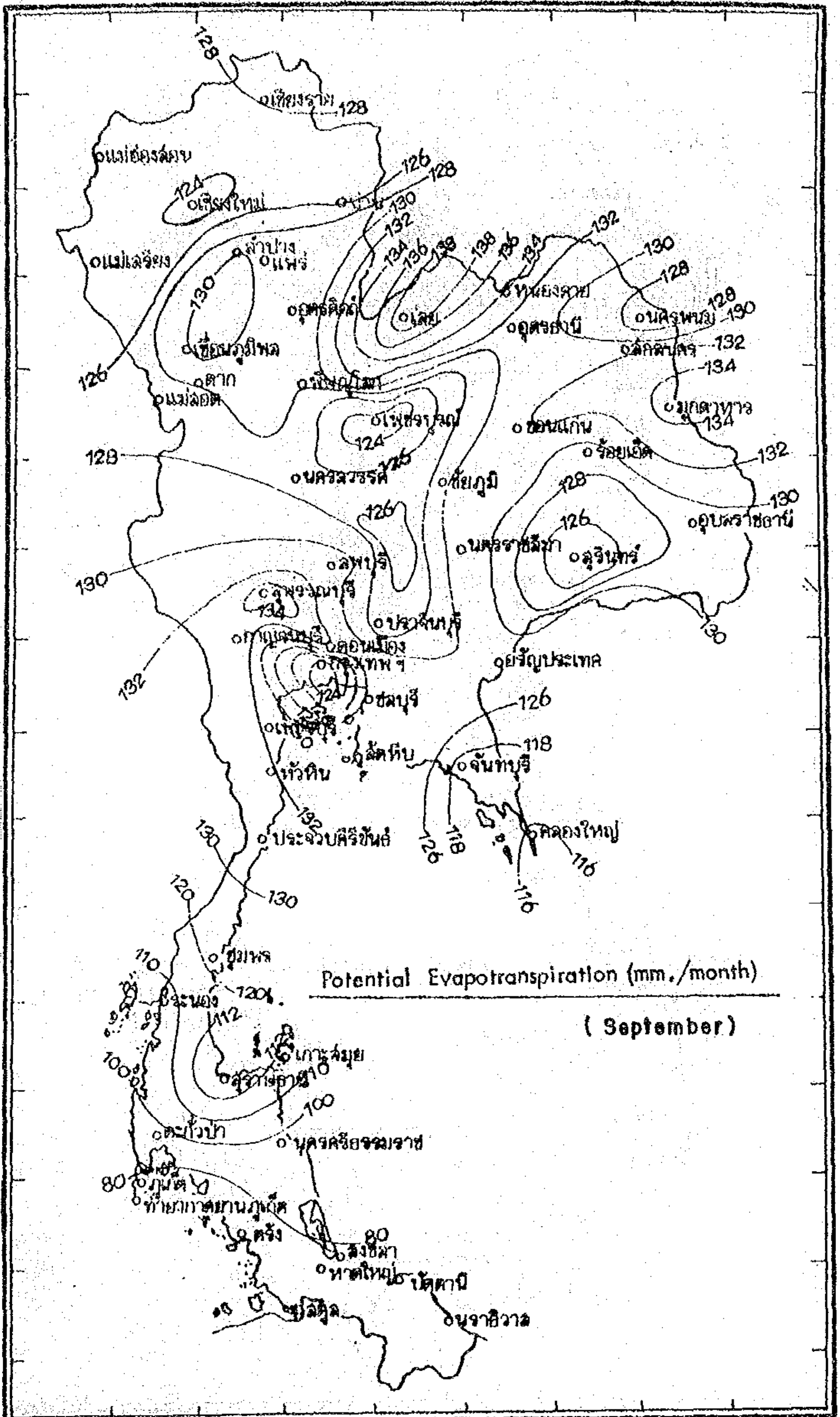

Potential Evapotranspiration (mm./month)
(June)

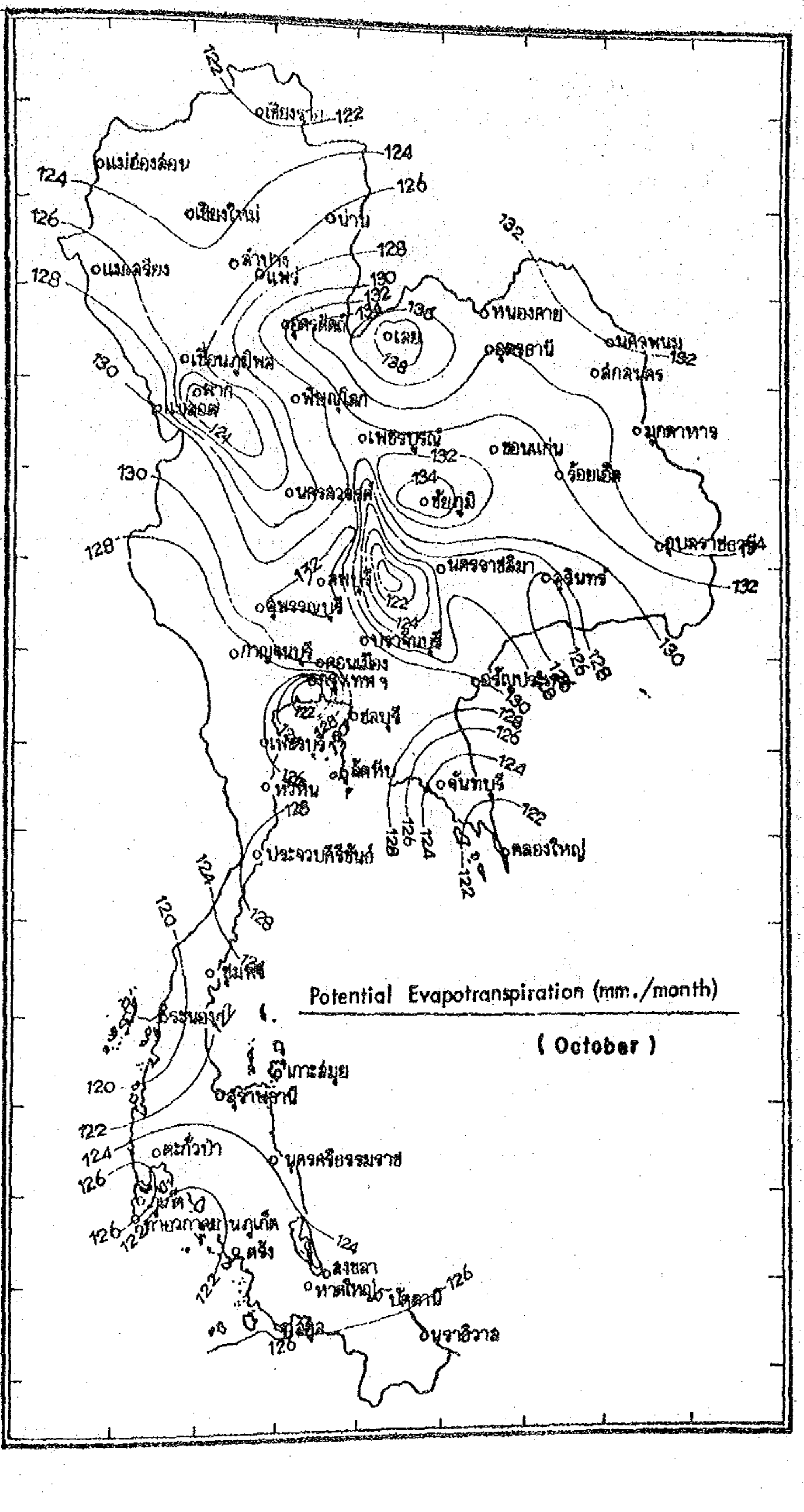


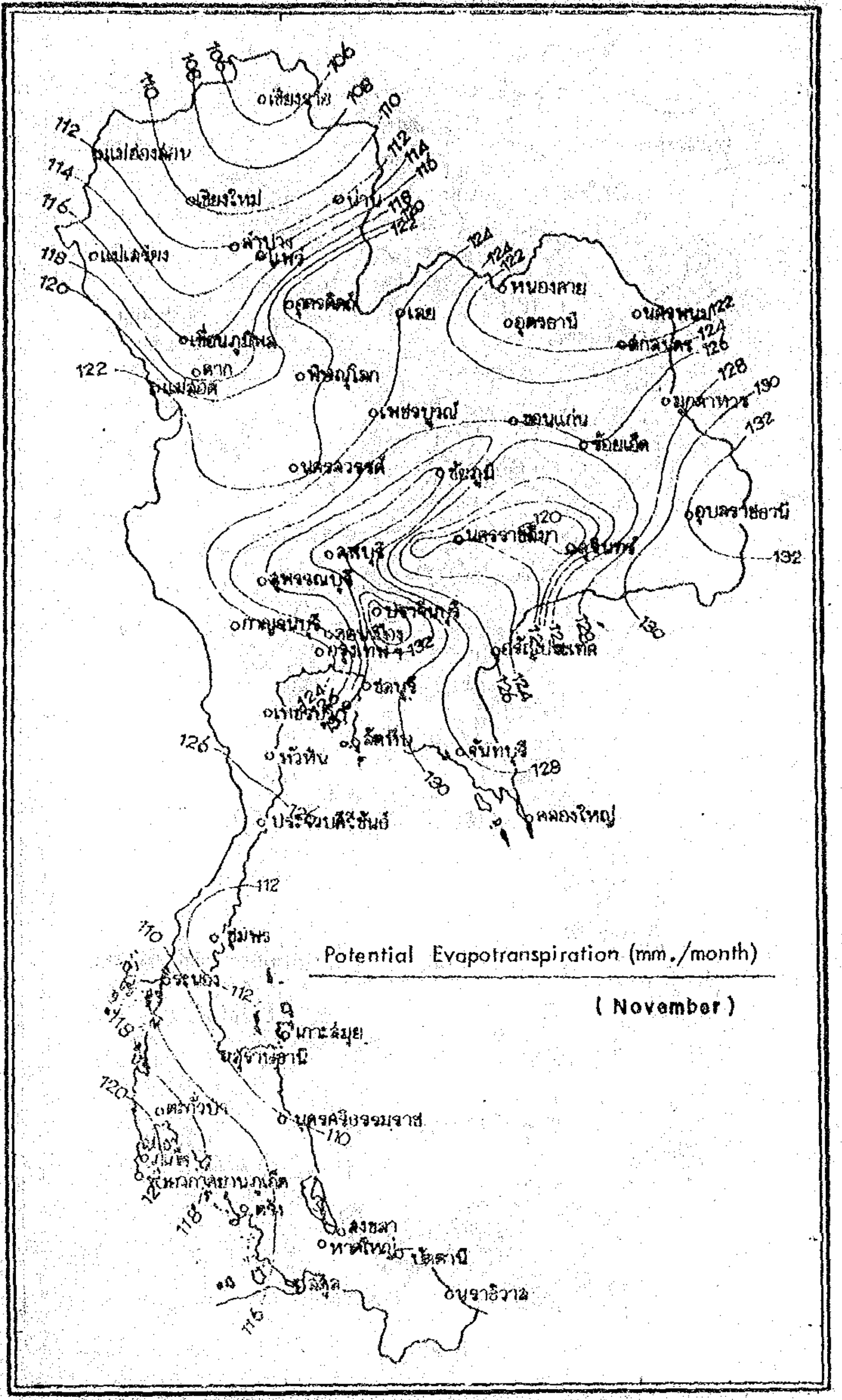
Potential Evapotranspiration (mm./month)

(July)


Potential Evapotranspiration (mm./month)
(August)
เชียงราย
น่าน
เลย
ขอนแก่น
ร้อยเอ็ด
ชัยภูมิ
มุกดาหาร
อุบลราชธานี
สุรินทร์
ชลบุรี
สัตหีบ
จันทบุรี
หัวหิน
ประจวบคีรีขันธ์
คลองใหญ่
ชุมพร
ตะกั่วป่า
ตรัง
สงขลา
หาดใหญ่
ปัตตานี
นราธิวาส

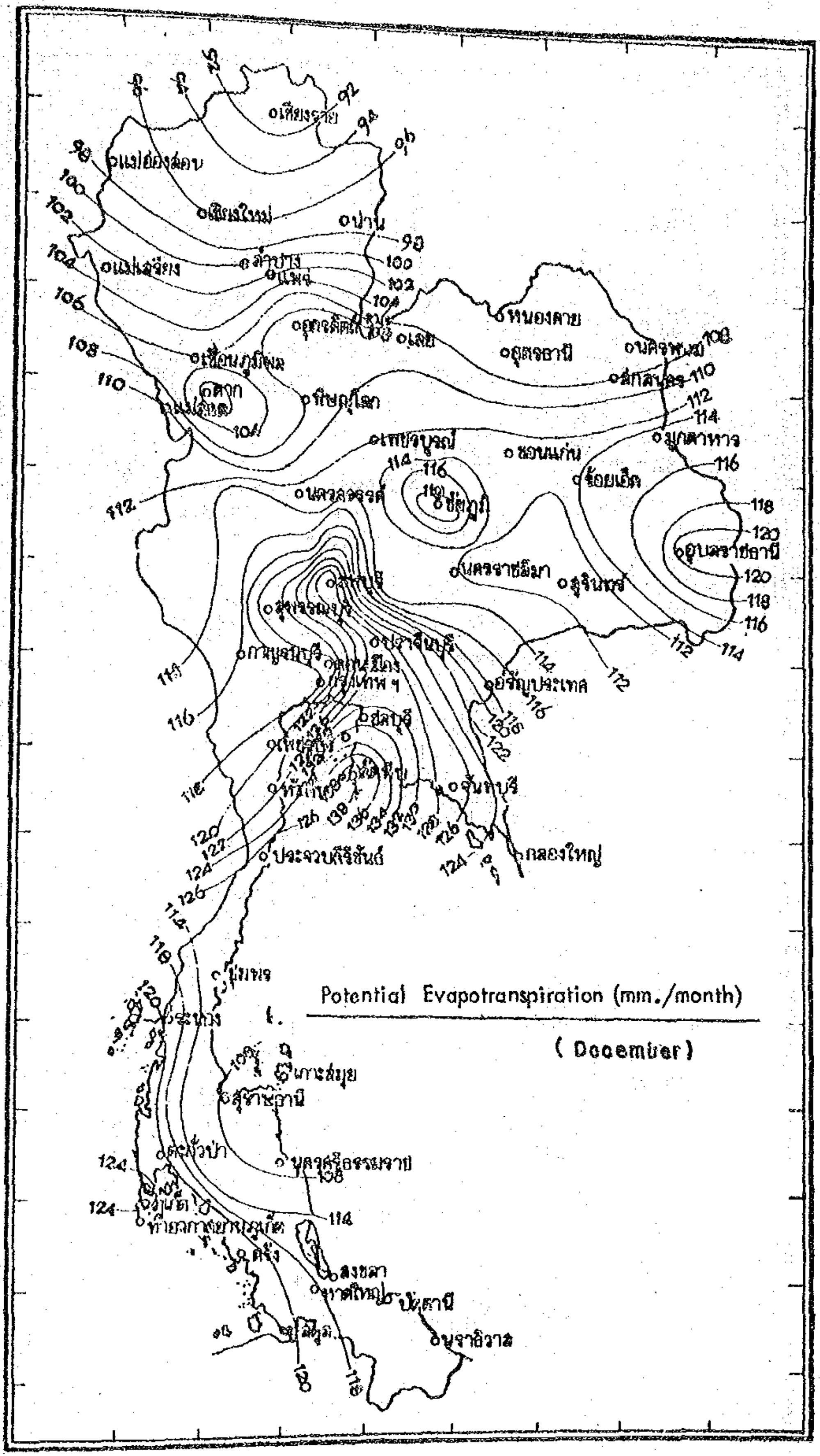

Potential Evapotranspiration (mm./month)
(September)


Potential Evapotranspiration (mm./month)
(October)



Potential Evapotranspiration (mm./month)

(November)


Potential Evapotranspiration (mm./month)
(December)