PERHITUNGAN KEBUTUHAN AIR TANAMAN (EVAPOTRANSPIRASI)

Capaian Pembelajaran

- Mahasiswa mampu menentukan besarnya evapotranspirasi tanaman referensi (ET_o) (kebutuhan air tanaman refrensi atau *crop water requirement*) dengan beberapa metode.
- Membandingkan metode-metode penghitungan Evapotranspirasi tanaman refrensi

Dasar Teori

Pada akhir tahun 1940-an diperkenalkanlah konsep Evapotranspirasi Potensial (PET), yaitu besar evapotranspirasi per satuan waktu tertentu untuk tanah yang sepenuhnya tertutup oleh tanaman budidaya hijau yang rendah. Tanah tersebut memiliki kadar air yang cukup (bukan tanah kering).

Pada awal tahun 1980-an, konsep ini dikoreksi, karena PET tidak langsung berkaitan dengan jenis tanaman tertentu. Muncullah konsep ET_o, dimana tanaman yang digunakan adalah rumput (alfalfa) hijau dengan tinggi yang seragam dan menutupi permukaan tanah dengan kadar air yang cukup (tidak kering). Nilai ET_o disebut nilai evapotranspirasi tanaman referensi (*reference evapotranspiration*). ET_o tanaman-tanaman lain diperoleh dengan mengalikan sebuah konstanta koefisien tanaman (k_c).

Penentuan besarnya nilai kebutuhan air tanaman bisa dihitung berdasarkan persamaan empiris yang telah dikembangkan oleh beberapa peneliti, maupun pengukuran secara langsung di lapangan. Modifikasi formula empiris tersebut banyak dilakukan oleh peneliti dengan mempertimbangkan ketersediaan data klimatologi, ketelitian hasil perhitungan, tujuan pemanfaatan, nilai kebutuhan tanaman tersebut dan lain-lain. Beberapa formulasi yang telah dikenal diantaranya adalah metode Blaney-Criddle, Penman, Radiasi, dll, yang mempunyai kelebihan dan kekurangan masing-masing.
Pada Praktikum ini akan dibahas beberapa metode diantaranya :

1. Metode Blaney Criddle
2. Metode Radiasi
3. Metode Penman-Monteith
4. Metode Pan Evaporation

1. Metode Blaney-Criddle

Persamaan asli Blaney-Criddle (1950) memasukkan perhitungan faktor kebutuhan air konsumtif (f) dari temperatur rata-rata (T), and persentase (p) dari total jam penyinaran cerah tahunan dalam periode yang diinginkan ($f = p \cdot T/100$). Kemudian sebuah konstanta yang diperoleh secara empiris untuk kebutuhan konsumtif tanaman tertentu (K) juga diterapkan dalam perhitungan untuk memperoleh kebutuhan air konsumtif (CU), sehingga diperoleh rumus $CU = K \cdot f = K\ (p.T/100)$ dimana T dalam °F. CU didefinisikan sebagai **jumlah air yang secara potensial dibutuhkan untuk memenuhi kebutuhan evapotranspirasi.**
Namun karena pengaruh iklim terhadap kebutuhan air tidak cukup hanya dengan mempertimbangkan temperatur dan panjang hari, maka digunakan perhitungan yang masih

DR. ARDIANSYAH-UNSOED

menggunakan faktor T dan f, metode ini digunakan untuk menghitung Evapotranspirasi refrensi tanaman (ET_o)

$$ET_o = c \cdot [p \cdot (0.46T + 8)], \text{ mm/hari}$$

dimana :

ET_o = Evapotranspirasi refrensi tanaman dalam mm/hari untuk bulan yang diperhitungkan

T = Temperatur harian rata-rata dalam °C dalam bulan yang diperhitungkan

p = Persentase rata-rata harian dari total jam siang yang diperoleh dari tabel 1. untuk tiap bulan dan lintang yang diketahui.

c = Adjustment faktor yang tergantung dari kelembaban relatif (RH) minimum, jam hari cerah dan angin sepanjang siang

setelah menghitung ET_o, maka dapat ditentukan ET crop dengan mengalikan ET_o dan koefisien tanaman (k_c), atau dirumuskan :

$$ET_{crop} = k_c \cdot ET_o$$

Contoh Perhitungan

Diketahui :

Kairo, Republik Mesir, Latitude 30° N ; Altitude 95 m; Juli

Perhitungan :

Tmax	Σ Nilai Tmax harian /31	35° C
Tmin	Σ Nilai Tmin harian /31	22° C
Tharian rata-rata	Σ Trataan/31 atau [(Σ Tmax/31)+(Σ Tmin/31)]/2	28.5°C
p	dari Tabel 1 untuk 30°N	0.31
p(0.46T + 8)	0.31(0.46 x 28.5 + 8)	6.6 mm/hari
RHmin	Data Klimatologi	medium
n/N	Data Klimatologi	high to medium
U_2 siang hari	Data Klimatologi	moderate
ET_o	Gambar 1, Blok 5 (baris 2)	**8.0 mm/hari**

Yearly data (using measured temperature data)

	J	F	M	A	M	J	J	A	S	O	N	D
Tmean °C	14	15	17.5	21	25.5	27.5	28.5	28.5	26	24	20	15.5
p	0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
p(0.46T + 8)	3.5	3.8	4.4	5.2	6.2	6.7	6.6	6.4	5.7	5.0	4.2	3.5

using general information and references on humidity, sunshine and wind (Climates of Africa, Griffith, 1972):

	RHmin	n/N	U daytime	Block Fig. 1	Line Fig. 1
Oct-March	medium	medium	light/mod	V	1-2 1/
April-May	low/med	high/med	moderate	IV, V, I & II 1/	2
June-July	medium	high/med	moderate	II & V 1/	2
Aug-Sept	medium	high/med	light/mod	II & V 1/	1-2 1/

using Figure 1:

	J	F	M	A	M	J	J	A	S	O	N	D
ETo mm/day	2.8	3.3	4.1	6.5	8.0	8.2	8.0	7.2	6.2	4.6	3.5	2.7
mm/month	87	92	127	195	248	246	248	223	186	142	105	83

1/ interpolation required; for instance for May between Blocks IV, V, I and II of p(0.46T + 8) = 6.2 mm/day and ETo = (8.3 + 7.1 + 9.0 + 7.7) ÷ 4 = 8.0 mm/day.

ARDIANSYAH–UNSOED

Tabel 1 Persentase Harian Rata-Rata Panjang Hari Siang untuk Beberapa Latitude

Table 1 Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes

Latitude North / South[1]	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	.31*	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

Format untuk Kalkulasi dengan Metode Perhitungan Blaney-Criddle

Format for Calculation of Blaney-Criddle Method

DATA	Country: UAR Period: July	Place: Cairo	Latitude: 30°N Longitude: 30	Altitude: 95m
T mean 28.5°C	T mean	data	28.5	
latitude 30° month July	p	Table 1	0.31	
		calc p(0.46T + 8)	6.6	
RHmin %		estimate	med.	
n/N		estimate	high/med	
U_2 daytime m/sec		estimate	Mod.	
		Fig. 1 Block/line	II, E ; 2	
	ETo	Fig. 1	8.0	mm/day

Gambar 1. RH minimum dan Panjang Hari Siang, dan Kecepatan Angin Siang Hari

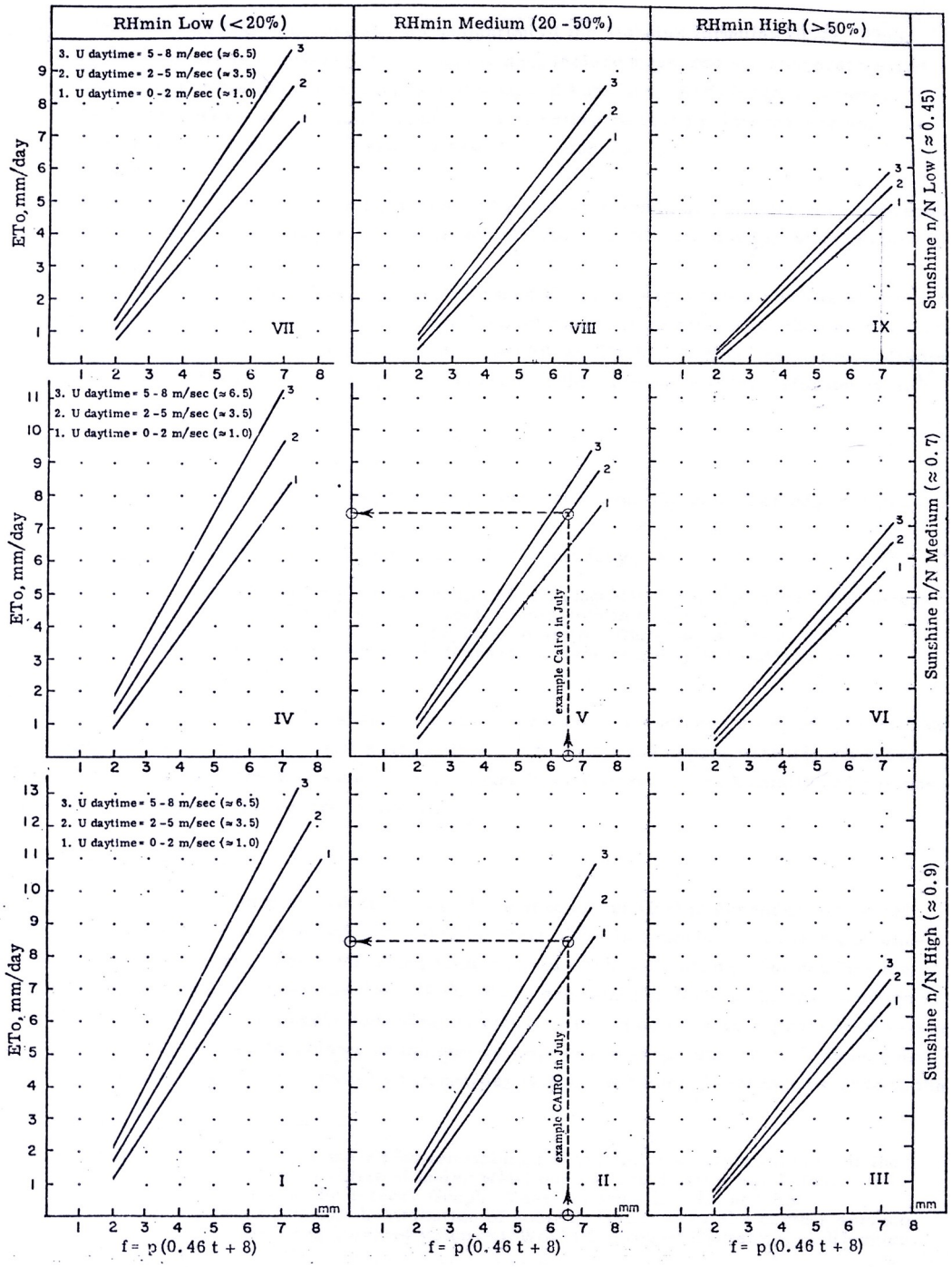


Fig. 1 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

2. Metode Radiasi

Metode Radiasi pada dasarnya adalah adaptasi dari Rumus Makkink (1957). Metode ini disarankan untuk daerah dimana data-data iklim yang tersedia termasuk temperatur udara, penyinaran matahari, keadaan awan atau radiasi, namun tidak termasuk kecepatan angin dan kelembaban. Dibandingkan dengan metode Blaney-Criddle, metode ini memberikan input yang lebih sedikit. Pada beberapa kasus untuk daerah equatorial, pulau kecil atau daerah yang punya altitude tinggi, Metode Radiasi lebih baik dari Metode Blaney-Criddle
Rumus yang direkomendasikan untuk Metode Radiasi adalah :

$$ET_o = c \cdot (W \cdot R_s), \text{ mm/hari}$$

dimana :

ET_o = Evapotranspirasi refrensi tanaman dalam mm/hari untuk periode yang diperhitungkan
R_s = Radiasi matahari dalam equivalen Evaporasi, mm/hari
W = Weighing factor yang tergantung dari Temperatur dan Altitude
c = Adjustment faktor yang tergantung dari kelembaban relatif (RH) rata-rata dan angin sepanjang siang

Untuk menghitung R_s dari lama penyinaran matahari (*sunshine duration*) atau radiasi surya, untuk menentukan weighing factor (W) dari temperatur dan altitude data, dan untuk memilih nilai c yang tepat berdasarkan hubungan antara $W.R_s$ dan ET_o pada gambar 2 untuk beberapa nilai kelembaban rata-rata dan kondisi angin siang hari, maka digunakan prosedur di bawah ini ;

a. Radiasi Surya
R_a adalah radiasi yang diterima oleh atmosfer yang paling atas, sebagian dari R_a diserap dan tersebar saat melewati atmosfer. Bagian dari R_a termasuk yang tersebar dan mengenai permukaan tanah diidentifikasi sebagai R_s.
R_s dapat diukur secara langsung, namun dapat juga dihitung dari data lama penyinaran seperti pada persamaan :
$R_s = (0.25 + 0.50\frac{n}{N}) \cdot R_a$ dimana n/N adalah rasio antara lama (jam) cerah dan kemungkinan maksimum jam cerah (*sunshine hours*). N diperoleh dari tabel 3. Data n diambil dari Campbell Stokes sunshine recorder. Nilai R_a untuk lintang dan bulan yang berbeda diberikan pada tabel 2.
Contoh :
Diketahui :
Kairo, Latitude 30°N, Juli, sunshine (n), rata-rata 1.5 jam/hari
Perhitungan :

R_a	dari Tabel 2.	= 6.8 mm/hari
N	dari Tabel 3.	= 3.9 mm/hari
R_s	(0.25 + 0.50 n/N)R_a	= (0.25 + 0.50 (11.5/3.9)) x 6.8
		= **11.2 mm/hari**

b. Weighting Factor (W)
Weighing factor menunjukkan efek temperature dan altitude terhadap hubungan antara R_s dan ET_o. Nilai W yang berkaitan dengan temperatur dan altitude diberikan di tabel 4.
Contoh :
Diketahui :

DR. ARDIANSYAH - UNSOED

Kairo, Altitude 95 m, Trata-rata : 28.5 °C

Perhitungan :

W dari Tabel 4. = **0.77**

c. Adjustment Factor (c)

Adjustment factor diberikan sebagai hubungan antara bagian radiasi ($W.R_s$) dan Evapotranpirasi refrensi tanaman (ET_o) ditunjukkan pada grafik gambar 2. Sebagian besar tergantung pada rata-rata RH dan kecepatan angin hari siang (*daytime wind*) (mulai jam 07.00 – 19.00) pada ketinggian 2 m dari permukaan tanah

Contoh :

Diketahui :

Kairo, latitude 30°, altitude 95 m, Juli, R_s = 1.2 mm/hari, W = 0.77, $W.R_s$ = 8.6 mm/hari, angin hari siang (*wind daytime*) = moderate, RH rata-rata = medium

Perhitungan :

Dari Gambar 2.	RH rata-rata	= medium
	Uday	= medium
ET_o	(untuk $W.R_s$ = 8.6 mm/hari)	= (8.7 + 8.0)/2
		= 8.4 mm/hari

Contoh Perhitungan

Diketahui :

Kairo, Republik Mesir, Latitude 30° N ; Altitude 95 m; Juli . Trata-rata = 28.5 °C, sunshine (n) rata-rata = 1.5 jam/hari; angin hari siang (*wind daytime*) U = moderate; Rhrata-rata = medium

Perhitungan :

R_a	dari Tabel 2.			6.8 mm/hari
R_s	(0.25 + 0.5 n/N) .R_a	n	=	11.5 jam/hari
		N	=	13.9 jam/hari
		n/N	=	0.83
		R_s	=	11.2 mm/hari
W	dari Tabel 4.			0.77
$W.R_s$				8.6 mm/hari
ET_o	dari Gambar 2, Blok II dan III			
	Baris 3			8.4 mm/hari

DR. ARDIANSYAH – UNSOED

Yearly data: Cairo, with solar radiation (Rs) given in mm/day.

	J	F	M	A	M	J	J	A	S	O	N	D
Tmean °C	14	15	17.5	21	25.5	27.5	28.5	28.5	26	24	20	15.5
Rs mm/day	5.0	6.4	8.5	9.9	10.9	11.4	11.2	10.4	9.1	7.1	5.5	4.6
RHmean	) III	III	III	II	II	II	av.II & III	av.II & III	III	III	av.III & IV	av. III & IV
Wind daytime	) av.)1&2	av. 1&2	av. 1&2	av. 1&2	2	2	2	av. 1&2	av. 1&2	av. 1&2	av. 1&2	av. 1&2
W	0.61	0.62	0.65	0.70	0.74	0.76	0.77	0.77	0.75	0.73	0.68	0.63
(W.Rs)	3.0	4.0	5.5	6.9	8.1	8.7	8.6	8.0	6.8	5.2	3.7	2.9
ETo mm/day	2.5	3.4	4.8	6.7	8.2	8.8	8.4	7.4	6.0	4.5	3.0	2.2
mm/month	78	95	149	201	254	264	260	229	180	140	90	68

Format untuk Kalkulasi dengan Metode Perhitungan Radiasi

Format for Calculation of Radiation Method

DATA	Country: U.A.R Period : July	Place: Cairo	Latitude : 30°N Longitude: 30	Altitude: 95 m
latitude 30°N month July	Ra mm/day	Table 2	16.8	
n mean 11.5 hr/d	n	data	11.5 ÷	
latitude 30°N month July	N	Table 3	13.9	
(or cloudiness)	n/N	calc or Table text	0.83	
	(0.25+0.50 n/N)	calc	0.67	
		calc	Rs 1/	11.2
Tmean 28.5 °C altitude 95 m	W	Table 4		0.77
		calc	W.Rs	8.6
RHmean %		estimate	med.	
U daytime m/sec		estimate	med.	
		Fig. 2	Block/line	II, III 2
			ETo mm/day	8.4

1/ as measured or obtained from regional or worldwide maps of solar radiation.

DR. ARDIANSYAH–U

Table 2 Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere												Lat	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Tabel 2. Radiasi Ekstra Terresterial (R_a) dinyatakan dalam Equivalen Evaporasi

Tabel 3. Durasi Harian Rata-Rata dari Maksimum Lama (Jam) Penyinaran yang Mungkin (N) untuk Bulan dan Latitude yang Berbeda

Tabel 4. Nilai Weighting Factor (W) sebagai Efek Radiasi pada ET_o pada Temperatur dan Altitud yang Berbeda

Table 3 Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats / Southern Lats	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
50	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1

Table 4 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.68	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.45	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.88	.88	.89
4 000	.55	.58	.61	.64	.66	.69	.71	.73	.76	.78	.79	.81	.83	.84	.85	.86	.88	.89	.90	.90

Gambar 2. Prediksi ET_o dari $W.R_s$ untuk beberapa Kondisi RH rata-rata dan Kecepatan Angin Hari Siang (*daytime wind*)

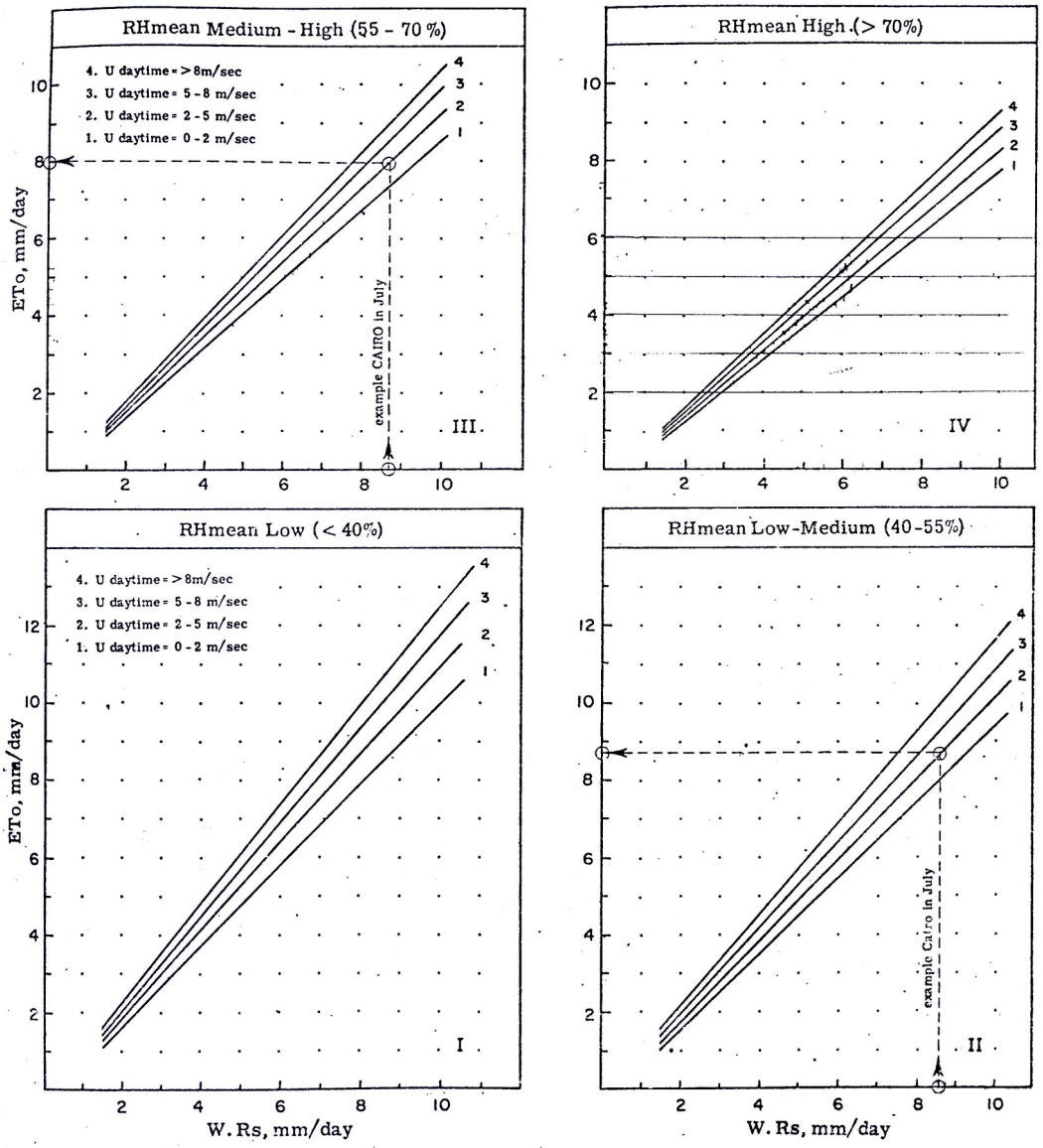


Fig. 2 Prediction of ETo from W. RS for different conditions of mean relative humidity and day time wind.

3. Metode Penman

Penman, pada tahun 1948 mengajukan persamaan untuk menghitung evapotranpirasi ;

$$E_o = \frac{\Delta H + \gamma E_a}{\Delta + \gamma}$$

dimana :

E_o = Evapotranspirasi refrensi tanaman dalam mm/hari untuk periode yang diperhitungkan
H = Faktor yang bergantung pada radiasi dan panjang penyinaran
E_a = Faktor yang tergantung pada kecepatan angin dan tekanan uap
Δ/γ = Parameter empiris yang bergantung pada temperatur

Penjabaran persamaan-persamaan tersebut dapat dicari pada berbagai literatur, namun untuk keperluan praktis telah dikembangkan nomogram yang mempermudah perhitungan. Prinsip nomogram tersebut adalah secara grafis memplot nilai-nilai yang diketahui sehingga diperoleh nilai E_o yang dicari.

Data-data input yang diperlukan untuk menghitung E_o menggunakan nomogram Penman adalah :

- Suhu udara rata-rata (t, °C)
- Kelembaban rata-rata (h)
- Penutupan langit oleh awan (n/D)
- Kecepatan angin rata-rata (u_2, m/s)
- Radiasi gelombang pendek (R_A, g/cal/cm^2/day)

Contoh Perhitungan

Diketahui suhu udara rata-rata = 18 °C

n/D = 0.4; R_A = 800 g cal/cm2/day; h = 0.6; u_2 = 3 m/s

maka penyelesaian penggunakan nomogram adalah

$$E_o = E_1 + E_2 + E_3 + E_4$$

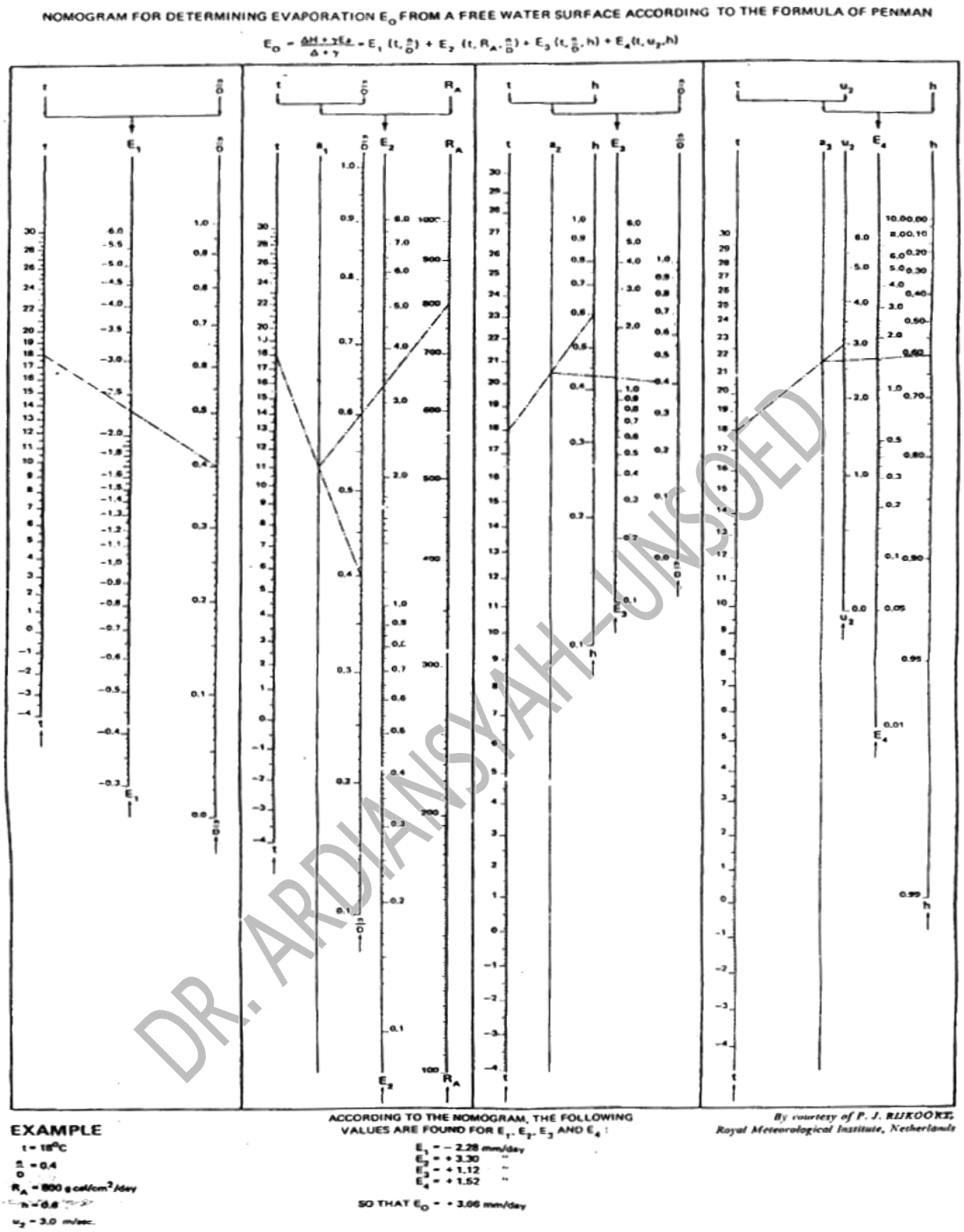
E_1 diperoleh dengan menarik garis antara t dan n/D
E_2 diperoleh dengan menarik garis antara t dan n/D lalu hasilnya ditarik garis ke R_A
E_3 diperoleh dengan menarik garis antara t dan h, lalu hasilnya ditarik garis ke n/D
E_4 dieproeh dengan menarik garis antara t dan u_2, lalu hasilnya ditarik ke h
Cara menarik garis dapat dilihat pada Gambar 3.

Tabel 5. Nilai R_A (g cal/cm^2/day)

Ketinggian (derajat)	Jan.	Feb.	Mar.	Apr.	Mei	Jun.	Jul.	Agt.	Sep.	Okt.	Nov.	Des.	Tahun
U 90	0	0	55	518	903	1077	944	605	136	0	0	0	3540
80	0	3	143	518	875	1060	930	600	219	17	0	0	3660
60	86	234	424	687	866	983	892	714	494	258	113	55	4850
40	358	538	663	847	930	1001	941	843	719	528	397	318	6750
20	631	795	821	914	912	947	912	887	856	740	666	599	8070
Kutub	844	963	878	876	803	803	792	820	891	866	873	829	8540
20	970	1020	832	737	608	580	588	680	820	892	986	978	8070
40	998	963	686	515	358	308	333	453	648	817	994	1033	6750
60	947	802	459	240	95	50	77	187	403	648	920	1013	4850
80	981	649	181	9	0	0	0	0	113	459	917	1094	3660
S 90	995	656	92	0	0	0	0	0	30	447	932	1110	3540

DR. ARDIANSYAH–UNSOED

Gambar 3. Nomogram Penman



DR. ARDIANSYAH – UNSOED

3. Metode Penman-Monteith

Untuk daerah dimana tersedia data-data temperature, kelembaban, angin dan durasi hari cerah, atau radiasi, maka adaptasi dari metode Penmann sangat disarankan. Metode Penman pertama kali diintroduksi pada tahun 1948. Namun dalam perkembangannya, metode ini disempurnakan oleh Monteith.

Metode Penman-Monteith yang diadaptasi oleh FAO dipertahankan sebagai standar untuk menghitung ET_o dari data meteorologi

$$ET_o = \frac{0.408 \cdot \Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 \cdot u_2)}, \text{ mm/hari}$$

dimana :

ET_o	= Evapotranspirasi refrensi tanaman dalam mm/hari untuk periode yang diperhitungkan
R_n	= Radiasi matahari Net pada permukaan tanaman (MJ/m.hari)
G	= Kerapatan flux panas pada tanah (MJ/m.hari)
T	= Temperatur udara pada ketinggian 2 m (^oC)
u_2	= Kecepatan angin pada ketinggian 2 m dari permukaan (m/detik)
e_s	= Tekanan uap jenuh (kPa)
e_a	= Tekanan uap aktual (kPa)
e_s-e_a	= Defisit tekanan uap jenuh (kPa)
Δ	= Kemiringan kurva tekanan uap (kPa/^oC)
γ	= Konstanta psikrometrik (kPa/^oC)

DR. ARDIANSYAH–UNSOED

BOX 11
Calculation sheet for ET_o (FAO Penman-Monteith) using meteorological tables of Annex 2

Parameters

T_{max}		°C			
T_{min}		°C	$T_{mean} = (T_{max}+T_{min})/2$		°C
T_{mean}		°C	Δ (Table 2.4 of Annex 2)		kPa/°C
Altitude		m	γ (Table 2.2 of Annex 2)		kPa/°C
u_2		m/s	$(1 + 0.34\ u_2)$		
$\Delta\ /\ [\Delta\ +\ \gamma\ (1 + 0.34\ u_2)]$					
$\gamma\ /\ [\Delta\ +\ \gamma\ (1 + 0.34\ u_2)]$					
$[\ 900\ /\ (T_{mean}\ +\ 273)\ ]\ u_2$					

Vapour pressure deficit

T_{max}		°C	$e°(T_{max})$ (Table 2.3)		kPa
T_{min}		°C	$e°(T_{min})$ (Table 2.3)		kPa
Saturation vapour pressure			$e_s = [(e°(T_{max}) + e°(T_{min})]/2$		kPa
e_a derived from dewpoint temperature:					
T_{dew}		°C	$e_a = e°(T_{dew})$ (Table 2.3)		kPa
OR e_a derived from maximum and minimum relative humidity:					
RH_{max}		%	$e°(T_{min})\ RH_{max}/100$		kPa
RH_{min}		%	$e°(T_{max})\ RH_{min}/100$		kPa
			e_a: (average)		kPa
OR e_a derived from maximum relative humidity: (recommended if there are errors in RH_{min})					
RH_{max}		%	$e_a = e°(T_{min})\ RH_{max}/100$		kPa
OR e_a derived from mean relative humidity: (less recommended due to non-linearities)					
RH_{mean}		%	$e_a = e_s\ RH_{mean}/100$		kPa
Vapour pressure deficit			**$(e_s - e_a)$**		kPa

Radiation					
Latitude		°			
Day			R_a (Table 2.6)		MJ m^{-2} d^{-1}
Month			N (Table 2.7)		hours
n		hours	n/N		
If no R_s data available: $R_s = (0.25 + 0.50\ n/N)\ R_a$					MJ m^{-2} d^{-1}
$R_{so} = [0.75 + 2\ (Altitude)/\ 100\ 000]\ R_a$					MJ m^{-2} d^{-1}
R_s / R_{so}					
$R_{ns} = 0.77\ R_s$					MJ m^{-2} d^{-1}
T_{max}			$\sigma\ T_{max,K}^4$ (Table 2.8)		MJ m^{-2} d^{-1}
T_{min}			$\sigma\ T_{min,K}^4$ (Table 2.8)		MJ m^{-2} d^{-1}
$(\sigma T_{max,K}^4 + \sigma T_{min,K}^4)/2$					MJ m^{-2} d^{-1}
e_a		kPa	$(0.34 - 0.14\ \sqrt{e_a})$		
R_s/R_{so}			$(1.35\ R_s/R_{so} - 0.35)$		
$R_{nl} = (\sigma T_{max,K}^4 + \sigma T_{min,K}^4)/2\ \ (0.34 - 0.14\ \sqrt{e_a})\ \ (1.35\ R_s/R_{so} - 0.35)$					MJ m^{-2} d^{-1}
$R_n = R_{ns} - R_{nl}$					MJ m^{-2} d^{-1}
T_{month}		°C	G_{day} (assume)	0	MJ m^{-2} d^{-1}
$T_{month-1}$		°C	$G_{month} = 0.14\ (T_{month} - T_{month-1})$		MJ m^{-2} d^{-1}
$R_n - G$					MJ m^{-2} d^{-1}
$0.408\ (R_n - G)$					mm/day

Grass reference evapotranspiration		
$\left[\frac{\Delta}{\Delta + \gamma(1 + 0.34\,u_2)}\right]\ [0.408\ (R_n - G)]$		mm/day
$\left[\frac{\gamma}{\Delta + \gamma(1 + 0.34\,u_2)}\right]\left[\frac{900}{T + 273}\right]\ u_2\ [(e_s - e_a)]$		mm/day
$ET_o = \frac{0.408\Delta\ (R_n - G) + \gamma \frac{900}{T + 273}\ u_2\ (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$		mm/day

measured at standard height of 2 m above ground surface

TABLE 2.1
Atmospheric pressure (P) for different altitudes (z)

$$P = 101.3\left(\frac{293 - 0.0065\,z}{293}\right)^{5.26} \qquad \textbf{(Eq. 7)}$$

Z (m)	P (kPa)	z (m)	P (kPa)	z (m)	P (kPa)	z (m)	P (kPa)
0	101.3	1000	90.0	2000	79.8	3000	70.5
50	100.7	1050	89.5	2050	79.3	3050	70.1
100	100.1	1100	89.0	2100	78.8	3100	69.6
150	99.5	1150	88.4	2150	78.3	3150	69.2
200	99.0	1200	87.9	2200	77.9	3200	68.8
250	98.4	1250	87.4	2250	77.4	3250	68.3
300	97.8	1300	86.8	2300	76.9	3300	67.9
350	97.2	1350	86.3	2350	76.4	3350	67.5
400	96.7	1400	85.8	2400	76.0	3400	67.1
450	96.1	1450	85.3	2450	75.5	3450	66.6
500	95.5	1500	84.8	2500	75.0	3500	66.2
550	95.0	1550	84.3	2550	74.6	3550	65.8
600	94.4	1600	83.8	2600	74.1	3600	65.4
650	93.8	1650	83.3	2650	73.7	3650	65.0
700	93.3	1700	82.8	2700	73.2	3700	64.6
750	92.7	1750	82.3	2750	72.7	3750	64.1
800	92.2	1800	81.8	2800	72.3	3800	63.7
850	91.6	1850	81.3	2850	71.8	3850	63.3
900	91.1	1900	80.8	2900	71.4	3900	62.9
950	90.6	1950	80.3	2950	71.0	3950	62.5
1000	90.0	2000	79.8	3000	70.5	4000	62.1

TABLE 2.2
Psychrometric constant (γ) for different altitudes (z)

$$\gamma = \frac{c_p\,P}{\varepsilon\,\lambda} = 0.665 \times 10^{-3}\;P \qquad \textbf{(Eq. 8)}$$

Z (m)	γ kPa/°C	z (m)	γ kPa/°C	z (m)	γ kPa/°C	z (m)	γ kPa/°C
0	0.067	1000	0.060	2000	0.053	3000	0.047
100	0.067	1100	0.059	2100	0.052	3100	0.046
200	0.066	1200	0.058	2200	0.052	3200	0.046
300	0.065	1300	0.058	2300	0.051	3300	0.045
400	0.064	1400	0.057	2400	0.051	3400	0.045
500	0.064	1500	0.056	2500	0.050	3500	0.044
600	0.063	1600	0.056	2600	0.049	3600	0.043
700	0.062	1700	0.055	2700	0.049	3700	0.043
800	0.061	1800	0.054	2800	0.048	3800	0.042
900	0.061	1900	0.054	2900	0.047	3900	0.042
1000	0.060	2000	0.053	3000	0.047	4000	0.041

Based on λ= 2.45 MJ kg^{-1} at 20°C.

TABLE 2.3
Saturation vapour pressure ($e^o(T)$) for different temperatures (T)

$$e^o(T) = 0.6108 \exp\left[\frac{17.27\,T}{T + 237.3}\right] \qquad \text{(Eq. 11)}$$

T °C	e_s kPa	T °C	$e^o(T)$ kPa	T °C	$e^o(T)$ kPa	T °C	e_s kPa
1.0	0.657	13.0	1.498	25.0	3.168	37.0	6.275
1.5	0.681	13.5	1.547	25.5	3.263	37.5	6.448
2.0	0.706	14.0	1.599	26.0	3.361	38.0	6.625
2.5	0.731	14.5	1.651	26.5	3.462	38.5	6.806
3.0	0.758	15.0	1.705	27.0	3.565	39.0	6.991
3.5	0.785	15.5	1.761	27.5	3.671	39.5	7.181
4.0	0.813	16.0	1.818	28.0	3.780	40.0	7.376
4.5	0.842	16.5	1.877	28.5	3.891	40.5	7.574
5.0	0.872	17.0	1.938	29.0	4.006	41.0	7.778
5.5	0.903	17.5	2.000	29.5	4.123	41.5	7.986
6.0	0.935	18.0	2.064	30.0	4.243	42.0	8.199
6.5	0.968	18.5	2.130	30.5	4.366	42.5	8.417
7.0	1.002	19.0	2.197	31.0	4.493	43.0	8.640
7.5	1.037	19.5	2.267	31.5	4.622	43.5	8.867
8.0	1.073	20.0	2.338	32.0	4.755	44.0	9.101
8.5	1.110	20.5	2.412	32.5	4.891	44.5	9.339
9.0	1.148	21.0	2.487	33.0	5.030	45.0	9.582
9.5	1.187	21.5	2.564	33.5	5.173	45.5	9.832
10.0	1.228	22.0	2.644	34.0	5.319	46.0	10.086
10.5	1.270	22.5	2.726	34.5	5.469	46.5	10.347
11.0	1.313	23.0	2.809	35.0	5.623	47.0	10.613
11.5	1.357	23.5	2.896	35.5	5.780	47.5	10.885
12.0	1.403	24.0	2.984	36.0	5.941	48.0	11.163
12.5	1.449	24.5	3.075	36.5	6.106	48.5	11.447

TABLE 2.4
Slope of vapour pressure curve (Δ) for different temperatures (T)

$$\Delta = \frac{4098\left[0.6108 \exp\left(\frac{17.27\,T}{T + 237.3}\right)\right]}{(T + 237.3)^2} \qquad \text{(Eq. 13)}$$

T °C	Δ kPa/°C	T °C	Δ kPa/°C	T °C	Δ kPa/°C	T °C	Δ kPa/°C
1.0	0.047	13.0	0.098	25.0	0.189	37.0	0.342
1.5	0.049	13.5	0.101	25.5	0.194	37.5	0.350
2.0	0.050	14.0	0.104	26.0	0.199	38.0	0.358
2.5	0.052	14.5	0.107	26.5	0.204	38.5	0.367
3.0	0.054	15.0	0.110	27.0	0.209	39.0	0.375
3.5	0.055	15.5	0.113	27.5	0.215	39.5	0.384
4.0	0.057	16.0	0.116	28.0	0.220	40.0	0.393
4.5	0.059	16.5	0.119	28.5	0.226	40.5	0.402
5.0	0.061	17.0	0.123	29.0	0.231	41.0	0.412
5.5	0.063	17.5	0.126	29.5	0.237	41.5	0.421
6.0	0.065	18.0	0.130	30.0	0.243	42.0	0.431
6.5	0.067	18.5	0.133	30.5	0.249	42.5	0.441
7.0	0.069	19.0	0.137	31.0	0.256	43.0	0.451
7.5	0.071	19.5	0.141	31.5	0.262	43.5	0.461
8.0	0.073	20.0	0.145	32.0	0.269	44.0	0.471
8.5	0.075	20.5	0.149	32.5	0.275	44.5	0.482
9.0	0.078	21.0	0.153	33.0	0.282	45.0	0.493
9.5	0.080	21.5	0.157	33.5	0.289	45.5	0.504
10.0	0.082	22.0	0.161	34.0	0.296	46.0	0.515
10.5	0.085	22.5	0.165	34.5	0.303	46.5	0.526
11.0	0.087	23.0	0.170	35.0	0.311	47.0	0.538
11.5	0.090	23.5	0.174	35.5	0.318	47.5	0.550
12.0	0.092	24.0	0.179	36.0	0.326	48.0	0.562
12.5	0.095	24.5	0.184	36.5	0.334	48.5	0.574

TABLE 2.5
Number of the day in the year (J)

Day	January	February	March*	April*	May*	June*
1	1	32	60	91	121	152
2	2	33	61	92	122	153
3	3	34	62	93	123	154
4	4	35	63	94	124	155
5	5	36	64	95	125	156
6	6	37	65	96	126	157
7	7	38	66	97	127	158
8	8	39	67	98	128	159
9	9	40	68	99	129	160
10	10	41	69	100	130	161
	11	42	70	101	131	162
11	12	43	71	102	132	163
12	13	44	72	103	133	164
13	14	45	73	104	134	165
14	15	46	74	105	135	166
15	16	47	75	106	136	167
16	17	48	76	107	137	168
17	18	49	77	108	138	169
18	19	50	78	109	139	170
19	20	51	79	110	140	171
20	21	52	80	111	141	172
	22	53	81	112	142	173
21	23	54	82	113	143	174
22	24	55	83	114	144	175
23	25	56	84	115	145	176
24	26	57	85	116	146	177
25	27	58	86	117	147	178
26	28	59	87	118	148	179
27	29	(60)	88	119	149	180
28	30	-	89	120	150	181
29	31	-	90	-	151	-
30						
31						

TABLE 2□ add 1 if leap year

J can be determined for each day (D) of month (M) by
J = **INTEGER**(275 M/9 – 30 + D) – 2
IF (M < 3) **THEN** J = J + 2
also, **IF** (leap year and (M > 2)) **THEN** J = J + 1

For ten-day calculations, compute J for day D = 5, 15 and 25
For monthly calculations, J at the middle of the month is approximately given by
J = **INTEGER**(30.4 M – 15)

DR. ARD

TABLE 2.6. Daily extraterrestrial radiation (Ra) for different latitudes for the 15th day of the month[1]

TABLE 2.6. Daily extraterrestrial radiation (R_a) for different latit

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad \text{(Eq. 21)}$$

(values in MJ m^{-2} day^{-1})[2]

Northern Hemisphere													Lat.	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	deg.	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
0.0	2.6	10.4	23.0	35.2	42.5	39.4	28.0	14.9	4.9	0.1	0.0	70	41.4	28.6	15.8	4.9	0.2	0.0	0.0	2.2	10.7	23.5	37.3	45.3
0.1	3.7	11.7	23.9	35.3	42.0	38.9	28.6	16.1	6.0	0.7	0.0	68	41.0	29.3	16.9	6.0	0.8	0.0	0.0	3.2	11.9	24.4	37.4	44.7
0.6	4.8	12.9	24.8	35.6	41.4	38.8	29.3	17.3	7.2	1.5	0.1	66	40.9	30.0	18.1	7.2	1.5	0.1	0.5	4.2	13.1	25.4	37.6	44.1
1.4	5.9	14.1	25.8	35.9	41.2	38.8	30.0	18.4	8.5	2.4	0.6	64	41.0	30.8	19.3	8.4	2.4	0.6	1.2	5.3	14.4	26.3	38.0	43.9
2.3	7.1	15.4	26.6	36.3	41.2	39.0	30.6	19.5	9.7	3.4	1.3	62	41.2	31.5	20.4	9.6	3.4	1.2	2.0	6.4	15.5	27.2	38.3	43.9
3.3	8.3	16.6	27.5	36.6	41.2	39.2	31.3	20.6	10.9	4.4	2.2	60	41.5	32.3	21.5	10.8	4.4	2.0	2.9	7.6	16.7	28.1	38.7	43.9
4.3	9.6	17.7	28.4	37.0	41.3	39.4	32.0	21.7	12.1	5.5	3.1	58	41.7	33.0	22.6	12.0	5.5	2.9	3.9	8.7	17.9	28.9	39.1	44.0
5.4	10.8	18.9	29.2	37.4	41.4	39.6	32.6	22.7	13.3	6.7	4.2	56	42.0	33.7	23.6	13.2	6.6	3.9	4.9	9.9	19.0	29.8	39.5	44.1
6.5	12.0	20.0	30.0	37.8	41.5	39.8	33.2	23.7	14.5	7.8	5.2	54	42.2	34.3	24.6	14.4	7.7	4.9	6.0	11.1	20.1	30.6	39.9	44.3
7.7	13.2	21.1	30.8	38.2	41.6	40.1	33.8	24.7	15.7	9.0	6.4	52	42.5	35.0	25.6	15.6	8.8	6.0	7.1	12.2	21.2	31.4	40.2	44.4
8.9	14.4	22.2	31.5	38.5	41.7	40.2	34.4	25.7	16.9	10.2	7.5	50	42.7	35.6	26.6	16.7	10.0	7.1	8.2	13.4	22.2	32.1	40.6	44.5
10.1	15.7	23.3	32.2	38.8	41.8	40.4	34.9	26.6	18.1	11.4	8.7	48	42.9	36.2	27.5	17.9	11.1	8.2	9.3	14.6	23.3	32.8	40.9	44.5
11.3	16.9	24.3	32.9	39.1	41.9	40.6	35.4	27.5	19.2	12.6	9.9	46	43.0	36.7	28.4	19.0	12.3	9.3	10.4	15.7	24.3	33.5	41.1	44.6
12.5	18.0	25.3	33.5	39.3	41.9	40.7	35.9	28.4	20.3	13.9	11.1	44	43.2	37.2	29.3	20.1	13.5	10.5	11.6	16.8	25.2	34.1	41.4	44.6
13.8	19.2	26.3	34.1	39.5	41.9	40.8	36.3	29.2	21.4	15.1	12.4	42	43.3	37.7	30.1	21.2	14.6	11.6	12.8	18.0	26.2	34.7	41.6	44.6
15.0	20.4	27.2	34.7	39.7	41.9	40.8	36.7	30.0	22.5	16.3	13.6	40	43.4	38.1	30.9	22.3	15.8	12.8	13.9	19.1	27.1	35.3	41.8	44.6
16.2	21.5	28.1	35.2	39.9	41.8	40.8	37.0	30.7	23.6	17.5	14.8	38	43.4	38.5	31.7	23.3	16.9	13.9	15.1	20.2	28.0	35.8	41.9	44.5
17.5	22.6	29.0	35.7	40.0	41.7	40.8	37.4	31.5	24.6	18.7	16.1	36	43.4	38.9	32.4	24.3	18.1	15.1	16.2	21.2	28.8	36.3	42.0	44.4
18.7	23.7	29.9	36.1	40.0	41.6	40.8	37.6	32.1	25.6	19.9	17.3	34	43.4	39.2	33.0	25.3	19.2	16.2	17.4	22.3	29.6	36.7	42.0	44.3
19.9	24.8	30.7	36.5	40.0	41.4	40.7	37.9	32.8	26.6	21.1	18.5	32	43.3	39.4	33.7	26.3	20.3	17.4	18.5	23.3	30.4	37.1	42.0	44.1
21.1	25.8	31.4	36.8	40.0	41.2	40.6	38.0	33.4	27.6	22.2	19.8	30	43.1	39.6	34.3	27.2	21.4	18.5	19.6	24.3	31.1	37.5	42.0	43.9
22.3	26.8	32.2	37.1	40.0	40.9	40.4	38.2	33.9	28.5	23.3	21.0	28	43.0	39.8	34.8	28.1	22.5	19.7	20.7	25.3	31.8	37.8	41.9	43.6
23.4	27.8	32.8	37.4	39.9	40.6	40.2	38.3	34.5	29.3	24.5	22.2	26	42.8	39.9	35.3	29.0	23.5	20.8	21.8	26.3	32.5	38.0	41.8	43.3
24.6	28.8	33.5	37.6	39.7	40.3	39.9	38.3	34.9	30.2	25.5	23.3	24	42.5	40.0	35.8	29.8	24.6	21.9	22.9	27.2	33.1	38.3	41.7	43.0
25.7	29.7	34.1	37.8	39.5	40.0	39.6	38.4	35.4	31.0	26.6	24.5	22	42.2	40.1	36.2	30.6	25.6	23.0	24.0	28.1	33.7	38.4	41.4	42.6
26.8	30.6	34.7	37.9	39.3	39.5	39.3	38.3	35.8	31.8	27.7	25.6	20	41.9	40.0	36.6	31.3	26.6	24.1	25.0	28.9	34.2	38.6	41.2	42.1
27.9	31.5	35.2	38.0	39.0	39.1	38.9	38.2	36.1	32.5	28.7	26.8	18	41.5	40.0	37.0	32.1	27.5	25.1	26.0	29.8	34.7	38.7	40.9	41.7
28.9	32.3	35.7	38.1	38.7	38.6	38.5	38.1	36.4	33.2	29.6	27.9	16	41.1	39.9	37.2	32.8	28.5	26.2	27.0	30.6	35.2	38.7	40.6	41.2
29.9	33.1	36.1	38.1	38.4	38.1	38.1	38.0	36.7	33.9	30.6	28.9	14	40.6	39.7	37.5	33.4	29.4	27.2	27.9	31.3	35.6	38.7	40.2	40.6
30.9	33.8	36.5	38.0	38.0	37.6	37.6	37.8	36.9	34.5	31.5	30.0	12	40.1	39.6	37.7	34.0	30.2	28.1	28.9	32.1	36.0	38.6	39.8	40.0
31.9	34.5	36.9	37.9	37.6	37.0	37.1	37.5	37.1	35.1	32.4	31.0	10	39.5	39.3	37.8	34.6	31.1	29.1	29.8	32.8	36.3	38.5	39.3	39.4
32.8	35.2	37.2	37.8	37.1	36.3	36.5	37.2	37.2	35.6	33.3	32.0	8	38.9	39.0	37.9	35.1	31.9	30.0	30.7	33.4	36.6	38.4	38.8	38.7
33.7	35.8	37.4	37.6	36.6	35.7	35.9	36.9	37.3	36.1	34.1	32.9	6	38.3	38.7	38.0	35.6	32.7	30.9	31.5	34.0	36.8	38.2	38.2	38.0
34.6	36.4	37.6	37.4	36.0	35.0	35.3	36.5	37.3	36.6	34.9	33.9	4	37.6	38.3	38.0	36.0	33.4	31.8	32.3	34.6	37.0	38.0	37.6	37.2
35.4	37.0	37.8	37.1	35.4	34.2	34.6	36.1	37.3	37.0	35.6	34.8	2	36.9	37.9	38.0	36.4	34.1	32.6	33.1	35.2	37.1	37.7	37.0	36.4
36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6	0	36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6

DR

[1] Values for Ra on the 15th day of the month provide a good estimate (error < 1 %) of Ra averaged over all days within the month. Only for high latitudes greater than 55° (N or S) during winter months deviations may be more than 1%.

[2] Values can be converted to equivalent values in mm/day by dividing by Lambda = 2.45.

TABLE 2.7. Mean daylight hours (N) for different latitudes for the 15th of the month1

$$N = \frac{24}{\pi}\omega_s \quad \text{(Eq. 34)}$$

Northern Hemisphere												Lat. deg.	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
0.0	6.6	11.0	15.6	21.3	24.0	24.0	17.6	12.8	8.3	2.3	0.0	70	24.0	17.4	13.0	8.4	2.7	0.0	0.0	6.4	11.2	15.7	21.7	24.0
2.1	7.3	11.1	15.3	19.7	24.0	22.3	17.0	12.7	8.7	4.1	0.0	68	21.9	16.7	12.9	8.7	4.3	0.0	1.7	7.0	11.3	15.3	19.9	24.0
3.9	7.8	11.2	14.9	18.7	22.0	20.3	16.4	12.7	9.0	5.2	1.9	66	20.1	16.2	12.8	9.1	5.3	2.0	3.7	7.6	11.3	15.0	18.8	22.1
5.0	8.2	11.2	14.7	17.9	20.3	19.2	16.0	12.6	9.3	6.0	3.7	64	19.0	15.8	12.8	9.3	6.1	3.7	4.8	8.0	11.4	14.7	18.0	20.3
5.7	8.5	11.3	14.4	17.3	19.2	18.4	15.7	12.6	9.5	6.6	4.8	62	18.3	15.5	12.7	9.6	6.7	4.8	5.6	8.3	11.4	14.5	17.4	19.2
6.4	8.8	11.4	14.2	16.8	18.4	17.7	15.3	12.5	9.7	7.1	5.6	60	17.6	15.2	12.6	9.8	7.2	5.6	6.3	8.7	11.5	14.3	16.9	18.4
6.9	9.1	11.4	14.1	16.4	17.8	17.2	15.1	12.5	9.9	7.5	6.2	58	17.1	14.9	12.6	9.9	7.6	6.2	6.8	8.9	11.5	14.1	16.5	17.8
7.3	9.3	11.5	13.9	16.0	17.3	16.8	14.8	12.4	10.1	7.9	6.7	56	16.7	14.7	12.5	10.1	8.0	6.7	7.2	9.2	11.6	13.9	16.1	17.3
7.7	9.5	11.5	13.8	15.7	16.8	16.4	14.6	12.4	10.2	8.2	7.1	54	16.3	14.5	12.5	10.2	8.3	7.2	7.6	9.4	11.6	13.8	15.8	16.9
8.0	9.7	11.5	13.6	15.4	16.5	16.0	14.4	12.4	10.3	8.5	7.5	52	16.0	14.3	12.5	10.4	8.6	7.5	8.0	9.6	11.6	13.7	15.5	16.5
8.3	9.8	11.6	13.5	15.2	16.1	15.7	14.3	12.3	10.4	8.7	7.9	50	15.7	14.2	12.4	10.5	8.8	7.9	8.3	9.7	11.7	13.6	15.3	16.1
8.6	10.0	11.6	13.4	15.0	15.8	15.5	14.1	12.3	10.6	9.0	8.2	48	15.4	14.0	12.4	10.6	9.0	8.2	8.5	9.9	11.7	13.4	15.0	15.8
8.8	10.1	11.6	13.3	14.8	15.5	15.2	14.0	12.3	10.7	9.2	8.5	46	15.2	13.9	12.4	10.7	9.2	8.5	8.8	10.0	11.7	13.3	14.8	15.5
9.1	10.3	11.6	13.2	14.6	15.3	15.0	13.8	12.3	10.7	9.4	8.7	44	14.9	13.7	12.4	10.8	9.4	8.7	9.0	10.2	11.7	13.3	14.6	15.3
9.3	10.4	11.7	13.2	14.4	15.0	14.8	13.7	12.3	10.8	9.6	9.0	42	14.7	13.6	12.3	10.8	9.6	9.0	9.2	10.3	11.7	13.2	14.4	15.0
9.5	10.5	11.7	13.1	14.2	14.8	14.6	13.6	12.2	10.9	9.7	9.2	40	14.5	13.5	12.3	10.9	9.8	9.2	9.4	10.4	11.8	13.1	14.3	14.8
9.6	10.6	11.7	13.0	14.1	14.6	14.4	13.5	12.2	11.0	9.9	9.4	38	14.4	13.4	12.3	11.0	9.9	9.4	9.6	10.5	11.8	13.0	14.1	14.6
9.8	10.7	11.7	12.9	13.9	14.4	14.2	13.4	12.2	11.1	10.1	9.6	36	14.2	13.3	12.3	11.1	10.1	9.6	9.8	10.6	11.8	12.9	13.9	14.4
10.0	10.8	11.8	12.9	13.8	14.3	14.1	13.3	12.2	11.1	10.2	9.7	34	14.0	13.2	12.2	11.1	10.2	9.7	9.9	10.7	11.8	12.9	13.8	14.3
10.1	10.9	11.8	12.8	13.6	14.1	13.9	13.2	12.2	11.2	10.3	9.9	32	13.9	13.1	12.2	11.2	10.4	9.9	10.1	10.8	11.8	12.8	13.7	14.1
10.3	11.0	11.8	12.7	13.5	13.9	13.8	13.1	12.2	11.3	10.5	10.1	30	13.7	13.0	12.2	11.3	10.5	10.1	10.2	10.9	11.8	12.7	13.5	13.9
10.4	11.0	11.8	12.7	13.4	13.8	13.6	13.0	12.2	11.3	10.6	10.2	28	13.6	13.0	12.2	11.3	10.6	10.2	10.4	11.0	11.8	12.7	13.4	13.8
10.5	11.1	11.8	12.6	13.3	13.6	13.5	12.9	12.1	11.4	10.7	10.4	26	13.5	12.9	12.2	11.4	10.7	10.4	10.5	11.1	11.9	12.6	13.3	13.6
10.8	11.3	11.9	12.5	13.1	13.3	13.2	12.8	12.1	11.5	10.9	10.7	22	13.2	12.7	12.1	11.5	10.9	10.7	10.8	11.2	11.9	12.5	13.1	13.3
10.9	11.3	11.9	12.5	12.9	13.2	13.1	12.7	12.1	11.5	11.0	10.8	20	13.1	12.7	12.1	11.5	11.1	10.8	10.9	11.3	11.9	12.5	13.0	13.2
11.0	11.4	11.9	12.4	12.8	13.1	13.0	12.6	12.1	11.6	11.1	10.9	18	13.0	12.6	12.1	11.6	11.2	10.9	11.0	11.4	11.9	12.4	12.9	13.1
11.1	11.5	11.9	12.4	12.7	12.9	12.9	12.5	12.1	11.6	11.2	11.1	16	12.9	12.5	12.1	11.6	11.3	11.1	11.1	11.5	11.9	12.4	12.8	12.9
11.3	11.6	11.9	12.3	12.6	12.8	12.8	12.5	12.1	11.7	11.3	11.2	14	12.7	12.4	12.1	11.7	11.4	11.2	11.2	11.5	11.9	12.3	12.7	12.8
11.4	11.6	11.9	12.3	12.6	12.7	12.6	12.4	12.1	11.7	11.4	11.3	12	12.6	12.4	12.1	11.7	11.4	11.3	11.4	11.6	11.9	12.3	12.6	12.7
11.5	11.7	11.9	12.2	12.5	12.6	12.5	12.3	12.1	11.8	11.5	11.4	10	12.5	12.3	12.1	11.8	11.5	11.4	11.5	11.7	11.9	12.2	12.5	12.6
11.6	11.7	11.9	12.2	12.4	12.5	12.4	12.3	12.0	11.8	11.6	11.5	8	12.4	12.3	12.1	11.8	11.6	11.5	11.6	11.7	12.0	12.2	12.4	12.5
11.7	11.8	12.0	12.1	12.3	12.3	12.3	12.2	12.0	11.9	11.7	11.7	6	12.3	12.2	12.0	11.9	11.7	11.7	11.7	11.8	12.0	12.1	12.3	12.3
11.8	11.9	12.0	12.1	12.2	12.2	12.2	12.1	12.0	11.9	11.8	11.8	4	12.2	12.1	12.0	11.9	11.8	11.8	11.8	11.9	12.0	12.1	12.2	12.2
11.9	11.9	12.0	12.0	12.1	12.1	12.1	12.1	12.0	12.0	11.9	11.9	2	12.1	12.1	12.0	12.0	11.9	11.9	11.9	11.9	12.0	12.0	12.1	12.1
12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

[1] Values for N on the 15th day of the month provide a good estimate (error < 1 %) of N averaged over all days within the month. Only for high latitudes greater than 55° (N or S) during winter months deviations may be more than 1%.

TABLE 2.8
σT_K^4 (Stefan-Boltzmann law) at different temperatures (T)

With $\sigma = 4.903\ 10^{-9}$ MJ K^{-4} m^{-2} day^{-1}
and $T_K = T[°C] + 273.16$

T (°C)	σT_K^4 (MJ m^{-2} d^{-1})	T (°C)	σT_K^4 (MJ m^{-2} d^{-1})	T (°C)	σT_K^4 (MJ m^{-2} d^{-1})
1.0	27.70	17.0	34.75	33.0	43.08
1.5	27.90	17.5	34.99	33.5	43.36
2.0	28.11	18.0	35.24	34.0	43.64
2.5	28.31	18.5	35.48	34.5	43.93
3.0	28.52	19.0	35.72	35.0	44.21
3.5	28.72	19.5	35.97	35.5	44.50
4.0	28.93	20.0	36.21	36.0	44.79
4.5	29.14	20.5	36.46	36.5	45.08
5.0	29.35	21.0	36.71	37.0	45.37
5.5	29.56	21.5	36.96	37.5	45.67
6.0	29.78	22.0	37.21	38.0	45.96
6.5	29.99	22.5	37.47	38.5	46.26
7.0	30.21	23.0	37.72	39.0	46.56
7.5	30.42	23.5	37.98	39.5	46.85
8.0	30.64	24.0	38.23	40.0	47.15
8.5	30.86	24.5	38.49	40.5	47.46
9.0	31.08	25.0	38.75	41.0	47.76
9.5	31.30	25.5	39.01	41.5	48.06
10.0	31.52	26.0	39.27	42.0	48.37
10.5	31.74	26.5	39.53	42.5	48.68
11.0	31.97	27.0	39.80	43.0	48.99
11.5	32.19	27.5	40.06	43.5	49.30
12.0	32.42	28.0	40.33	44.0	49.61
12.5	32.65	28.5	40.60	44.5	49.92
13.0	32.88	29.0	40.87	45.0	50.24
13.5	33.11	29.5	41.14	45.5	50.56
14.0	33.34	30.0	41.41	46.0	50.87
14.5	33.57	30.5	41.69	46.5	51.19
15.0	33.81	31.0	41.96	47.0	51.51
15.5	34.04	31.5	42.24	47.5	51.84
16.0	34.28	32.0	42.52	48.0	52.16
16.5	34.52	32.5	42.80	48.5	52.49

DR. ARDIA

EXAMPLE 17
Determination of ET_o with mean monthly data

Given the monthly average climatic data of April of Bangkok (Thailand) located at 13 °44'N and at an elevation of 2 m:

-	Monthly average daily maximum temperature (T_{max}) =	34.8	°C
-	Monthly average daily minimum temperature (T_{min}) =	25.6	°C
-	Monthly average daily vapour pressure (e_a) =	2.85	kPa
Measured at 2 m	Monthly average daily wind speed (u_2) =	2	m/s
-	Monthly average sunshine duration (n) =	8.5	hours/day
For April	Mean monthly average temperature ($T_{month,i}$) =	30.2	°C
For March	Mean monthly average temperature ($T_{month,i-1}$) =	29.2	°C

Determination according to outline of Box 11 (calculation sheet ET_o)

Parameters			
-	T_{mean} = [(T_{max} = 34.8) + (T_{min} = 25.6)]/2 =	30.2	°C
From Table 2.4 or Eq. 13:	Δ =	0.246	kPa/°C
From Table 2.1 and Table 2.2 or Eq. 7 and Eq. 8:	Altitude =	2	m
	P =	101.3	kPa
	γ =	0.0674	kPa/°C
-	(1 + 0.34 u_2) =	1.68	-
-	$\Delta/[\Delta+\gamma(1+0.34u_2)]$ =0.246/[(0.246 + 0.0674 (1.68)] =	0.685	-
-	$\gamma/[\Delta+\gamma(1+0.34u_2)]$ = 0.0667/[0.246 + 0.0674 (1.68)] =	0.188	-
-	900/(T_{mean}+273) u_2 =	5.94	-

Vapour pressure deficit

From Table 2.3 or Eq. 11:	T_{max} =	34.8	°C
	$e°(T_{max})$ =	5.56	kPa
From Table 2.3 or Eq. 11:	T_{min} =	25.6	°C
	$e°(T_{min})$ =	3.28	kPa
-	e_s = (5.56 + 3.28)/2 =	4.42	kPa
Given	e_a =	2.85	kPa
-	Vapour pressure deficit (e_s-e_a) = (4.42 - 2.85) =	1.57	kPa

Radiation (for month = April)

From Table 2.6 or 2.5 or Eq. 21:	J = (for 15 April)	105	-
	Latitude = 13°44'N = (13 + 44/60)=	13.73	°N
	R_a =	38.06	MJ m^{-2} day^{-1}
N (Table 2.7 or Eq. 34):	Daylength N =	12.31	hours
-	n/N = (8.5/12.31) =	0.69	-
-	R_s = [0.25 + 0.50 (0.69)] 38.06 =	22.65	MJ m^{-2} day^{-1}
-	R_{so} = (0.75 + 2 (2)/100 000) 38.06 =	28.54	MJ m^{-2} day^{-1}
-	R_s/R_{so} = (22.65/28.54) =	0.79	-
-	R_{ns} = 0.77 (22.65) =	17.44	MJ m^{-2} day^{-1}
From Table 2.8:	T_{max} =	34.8	°C
	$\sigma T_{max} K^4$ =	44.10	MJ m^{-2} day^{-1}
From Table 2.8:	T_{min} =	25.6	°C
	$\sigma T_{min} K^4$ =	39.06	MJ m^{-2} day^{-1}
-	($\sigma T_{max} K^4$ + $\sigma T_{min} K^4$)/2 = (44.10 + 39.06)/2 =	41.58	MJ m^{-2} day^{-1}

4. Metode Pan Evaporation

Laju evaporasi dari panci yang diisi dengan air sangat mudah sekali untuk diteliti. Dengan tidak adanya hujan, jumlah air yang diuapkan selama periode tertentu (mm/hari) sebanding dengan penurunan air panci pada periode tersebut. Panci membutuhkan pengukuran yang terintegrasi antara efek radiasi, angin, temperatur, dan kelembaban dan penguapan dari permukaan air bebas. Walaupun respon panci terhadap faktor iklim terkadang sama dengan respon tanaman, namun perlu terdapat beberapa faktor yang signifikan yang menyebabkan keduanya berbeda.
Dengan adanya perbedaan antara pan-evaporation dengan permukaan tanaman, kegunaan panci untuk memprediksi ET_o untuk periode 10 hari atau lebih lama mungkin dapat mendekati.
Hubungan antara evaporasi panci dan evapotranspirasi refrensi (ET_o) dinyatakan dalam koefisien empiris sebagai berikut :

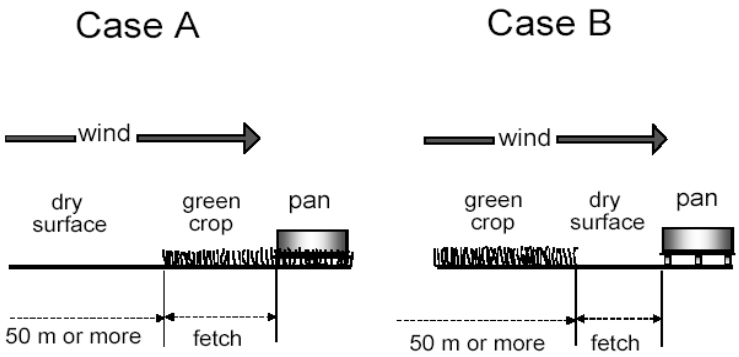
$$ET_o = K_p \cdot E_{pan}, \text{ mm/hari}$$

dimana :

ET_o = Evapotranspirasi refrensi (mm/hari)
K_p = Koefisien panci (-)
E_{pan} = Evaporasi panci (mm/hari)

Panci Evaporasi terdiri dari panci kelas A, dan Colorado Sunken Pan. Untuk memilih koefisien panci yang tepat, tidak hanya tergantung dari tipe panci tapi juga tergantung dari penutupan tanah oleh vegetasi pada stasiun pengukuran. Lingkungan sekitarnya seperti kecepatan angin dan kelembaban juga harus diperiksa. Ada dua kondisi panci pengukuran, dimana pada kasus A panci diletakkan pada lingkungan dengan rumput yang pendek dan disekitarnya adalah tanah kosong, sedangkan pada kasus B, panci diletakkan di tanah yang kosong dan disekitarnya terdapat penutupan tanah oleh vegetasi rumput

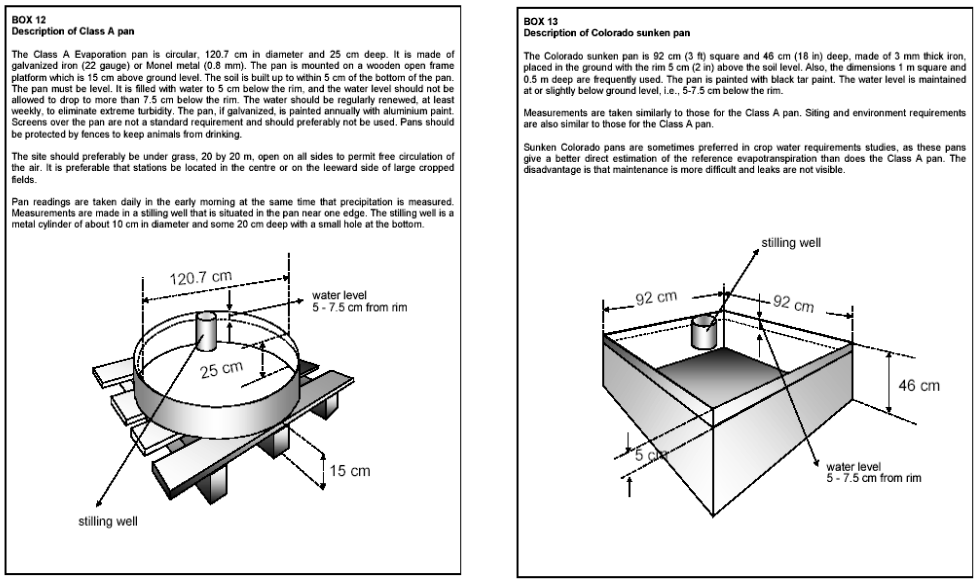
DR. ARDIANSYAH - UNSOED



Kondisi Peletakkan Panci Evaporasi

Koefisien Panci untuk Panci Kelas A dan Panci Colorado Sunken pada berbagai penutupan tanah, kondisi iklim, dan fetch (jarak tutupan permukaan yang teridentifikasi) diberikan pada tabel 5 dan tabel 6. Sedangkan tabel 7, merupakan persamaan regresi yang digunakan untuk menghitung koefisien panci dan diperoleh dari tabel 5 dan 6. Rasio antara Evaporasi yang diperoleh dengan menggunakan Panci Kelas A dan Colorado Sunken Pan pada beberapa kondisi iklim yang berbeda diberikan pada tabel 8.

UNSOED



BOX 12
Description of Class A pan

The Class A Evaporation pan is circular, 120.7 cm in diameter and 25 cm deep. It is made of galvanized iron (22 gauge) or Monel metal (0.8 mm). The pan is mounted on a wooden open frame platform which is 15 cm above ground level. The soil is built up to within 5 cm of the bottom of the pan. The pan must be level. It is filled with water to 5 cm below the rim, and the water level should not be allowed to drop to more than 7.5 cm below the rim. The water should be regularly renewed, at least weekly, to eliminate extreme turbidity. The pan, if galvanized, is painted annually with aluminium paint. Screens over the pan are not a standard requirement and should preferably not be used. Pans should be protected by fences to keep animals from drinking.

The site should preferably be under grass, 20 by 20 m, open on all sides to permit free circulation of the air. It is preferable that stations be located in the centre or on the leeward side of large cropped fields.

Pan readings are taken daily in the early morning at the same time that precipitation is measured. Measurements are made in a stilling well that is situated in the pan near one edge. The stilling well is a metal cylinder of about 10 cm in diameter and some 20 cm deep with a small hole at the bottom.

BOX 13
Description of Colorado sunken pan

The Colorado sunken pan is 92 cm (3 ft) square and 46 cm (18 in) deep, made of 3 mm thick iron, placed in the ground with the rim 5 cm (2 in) above the soil level. Also, the dimensions 1 m square and 0.5 m deep are frequently used. The pan is painted with black tar paint. The water level is maintained at or slightly below ground level, i.e., 5-7.5 cm below the rim.

Measurements are taken similarly to those for the Class A pan. Siting and environment requirements are also similar to those for the Class A pan.

Sunken Colorado pans are sometimes preferred in crop water requirements studies, as these pans give a better direct estimation of the reference evapotranspiration than does the Class A pan. The disadvantage is that maintenance is more difficult and leaks are not visible.

Deskripsi Panci Kelas A dan Colorado Sunken Pan

TABLE 5
Pan coefficients (K_p) for Class A pan for different pan siting and environment and different levels of mean relative humidity and wind speed (FAO Irrigation and Drainage Paper No. 24)

Class A pan	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area			
RH mean (%) →		low < 40	medium 40 -70	high > 70		low < 40	medium 40 -70	high > 70
Wind speed ($m\ s^{-1}$)	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light	1	.55	.65	.75	1	.7	.8	.85
< 2	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1 000	.75	.85	.85	1 000	.5	.6	.7
Moderate	1	.5	.6	.65	1	.65	.75	.8
2-5	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1 000	.7	.8	.8	1 000	.45	.55	.6
Strong	1	.45	.5	.6	1	.6	.65	.7
5-8	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1 000	.65	.7	.75	1 000	.4	.45	.55
Very strong	1	.4	.45	.5	1	.5	.6	.65
> 8	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1 000	.55	.6	.65	1 000	.35	.4	.45

TABLE 6
Pan coefficients (K_p) for Colorado sunken pan for different pan siting and environment and

	1 000	.55	.6	.65	1 000	.35	.4	.45

TABLE 6
Pan coefficients (K_p) for Colorado sunken pan for different pan siting and environment and different levels of mean relative humidity and wind speed (FAO Irrigation and Drainage Paper No. 24)

Sunken Colorado	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area (1)			
RH mean (%) →		low < 40	medium 40 -70	high > 70		low < 40	medium 40 -70	high > 70
Wind speed ($m\ s^{-1}$)	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light	1	.75	.75	.8	1	1.1	1.1	1.1
< 2	10	1.0	1.0	1.0	10	.85	.85	.85
	≥ 100	1.1	1.1	1.1	100	.75	.75	.8
					1 000	.7	.7	.75
Moderate	1	.65	.7	.7	1	.95	.95	.95
2-5	10	.85	.85	.9	10	.75	.75	.75
	≥ 100	.95	.95	.95	100	.65	.65	.7
					1 000	.6	.6	.65
Strong	1	.55	.6	.65	1	.8	.8	.8
5-8	10	.75	.75	.75	10	.65	.65	.65
	≥ 100	.8	.8	.8	100	.55	.6	.65
					1 000	.5	.55	.6
Very strong	1	.5	.55	.6	1	.7	.75	.75
> 8	10	.65	.7	.7	10	.55	.6	.65
	≥ 100	.7	.75	.75	100	.5	.55	.6
					1 000	.45	.5	.55

(1) For extensive areas of bare-fallow soils and no agricultural development, reduce K_{pan} by 20% under hot, windy conditions; by 5-10% for moderate wind, temperature and humidity conditions.

DR. AR

TABLE 7
Pan coefficients (K_p): regression equations derived from Tables 5 and 6

Class A pan with green fetch	$K_p = 0.108 - 0.0286\,u_2 + 0.0422\ln(FET) + 0.1434\ln(RH_{mean}) - 0.000631[\ln(FET)]^2\ln(RH_{mean})$
Class A pan with dry fetch	$K_p = 0.61 + 0.00341\,RH_{mean} - 0.000162\,u_2 RH_{mean} - 0.00000959\,u_2 FET + 0.00327\,u_2\ln(FET) - 0.00289\,u_2\ln(86.4u_2) - 0.0106\ln(86.4u_2)\ln(FET) + 0.00063[\ln(FET)]^2\ln(86.4u_2)$
Colorado sunken pan with green fetch	$K_p = 0.87 + 0.119\ln(FET) - 0.0157[\ln(86.4u_2)]^2 - 0.0019[\ln(FET)]^2\ln(86.4u_2) + 0.013\ln(86.4u_2)\ln(RH_{mean}) - 0.000053\ln(86.4u_2)\ln(FET)RH_{mean}$
Colorado sunken pan with dry fetch	$K_p = 1.145 - 0.080u_2 + 0.000903(u_2)^2\ln(RH_{mean}) - 0.0964\ln(FET) + 0.0031u_2\ln(FET) + 0.0015[\ln(FET)]^2\ln(RH_{mean})$
Coefficients and parameters	K_p pan coefficient [ ] u_2 average daily wind speed at 2 m height ($m\,s^{-1}$) RH_{mean} average daily relative humidity [%] = $(RH_{max} + RH_{min})/2$ FET fetch, or distance of the identified surface type (grass or short green agricultural crop for case A, dry crop or bare soil for case B upwind of the evaporation pan)
Range for variables	$1\ m \le FET \le 1\,000\ m$ (these limits must be observed) $30\% \le RH_{mean} \le 84\%$ $1\ m\,s^{-1} \le u_2 \le 8\ m\,s^{-1}$

TABLE 8
Ratios between the evaporation from sunken pans and a Colorado sunken pan for different climatic conditions and environments (FAO Irrigation and Drainage Paper No. 24)

		Ratio E_{pan} mentioned and E_{pan} Colorado			
Climate		Humid-temperate climate		Arid to semi-arid (dry season)	
Ground cover surrounding pan (50 m or more)		Short green cover	Dry fallow	Short green cover	Dry fallow
	Pan area (m^2)				
GGI 20 diameter 5 m, depth 2 m (former Soviet Union)	19.6	1.0	1.1	1.05	1.25
Sunken pan diameter 12 ft (3.66 m) depth 3.3 ft (Israel)	10.5				
BPI diameter 6 ft (1.83 m), depth 2 ft (0.61 m) (USA)	2.6				
Kenya pan diameter 4 ft (1.22 m) depth 14 in (0.356 m)	1.2				
Australian pan diameter 3 ft (0.91 m) depth 3 ft (0.91 m)	0.7		1.0		1.0
Symmons pan 6 ft^2 (0.56 m^2) depth 2 ft (0.61 m)	0.6				
Aslyng pan 0.33 m^2, depth 1 m (Denmark)	0.3			1.0	
GGI 3000 diameter 0.618 cm, depth 60-80 cm (former Soviet Union)	0.3				
Sunken pan diameter 50 cm, depth 25 cm (Netherlands)	0.2	1.0	0.95	1.0	0.95

EXAMPLE 21
Determination of ET_o from pan evaporation using tables

Given the daily evaporation data for the first week of July for a Class A pan installed in a green area surrounded by short irrigated field crops: 8.2, 7.5, 7.6, 6.8, 7.6, 8.9 and 8.5 mm/day. In that period the mean wind speed is 1.9 m/s and the daily mean relative humidity is 73%. Determine the 7-day average reference evapotranspiration.

Pan is installed on a green surface: Case A

Pan is surrounded by irrigated crops: Wind speed is light: Relative humidity is high:	$fetch_{max}$ = u < RH_{mean} >	1 000 2 70	m m/s %
From Table 5 (for above conditions):	K_p =	0.85	-
- From Eq. 55:	E_{pan} = (8.2+7.5+7.6+6.8+7.6+8.9+8.5)/7 = ET_o = 0.85 (7.9) =	7.9 6.7	mm/day mm/day

The 7-day average of the crop reference evapotranspiration is 6.7 mm/day

DR. ARDIANSYAH–UNSOED

TUGAS

Diketahui data klimatologi bulanan yang mencakup ; temperatur maksimum, temperatur minimum, (atau temperatur rata-rata sebagai penganti), kecepatan angin, fraksi hari cerah, ketinggian tanah (altitude), Lokasi (Latitude) suatu daerah tertentu

Carilah nilai evaporasi atau evapotranspirasi menggunakan beberapa metode yang diminta pada paragraf berikut :

Sebuah lokasi terletak pada 40° 30' North, dan ketinggian (altitude) 120 mdpl. Data-data iklim pada bulan Oktober, November, dan Desember diberikan pada tabel berikut :

Bulan	Suhu rata-rata harian t , ℃	Kelembaban rata-rata h	Kecepatan angin u_2 , m/s	Fraksi hari cerah n/D
	(1)	(2)	(3)	(4)
Oktober	14.4	0.54	0.8	0.41
November	8.3	0.20	1.3	0.28
Desember	3.9	0.56	1.7	0.25

Tentukan evapotransporasi dengan metode

a) Blaney Criddle (gunakan kolom (1) untuk T, dan Tabel 1 untuk nilai p)
b) Radiasi (gunakan kolom (1) untuk Trata-rata, kolom (2) untuk RH, dan kolom (3) untuk U, kolom 4 untuk n/N)
c) Nomogram Penman (gunakan kolom 1, 2, 3, dan 4, serta Tabel 5 untuk nilai R_A , gunakan nomogram Penman di Gambar 3)

Metode Penman-Monteith dan Panci Evaporasi tidak diminta mengerjakan (untuk pekan depan)

PUSTAKA

Dooren, J. 1977. Guidelines for Predicting Crop Water Requirement. FAO Irrigation and Drainage Paper.

Allen R.G., Luis S.P., Dirk R., Martin S. 1990. Crop Evapotranspiration, Guidelines for Predicting Crop Water Requirement. FAO Irrigation and Drainage Paper

DR. ARDIANSYAH – UNSOED