49302 72
PN-AAR-831
ISN = 38226

TECHNICAL NOTE

NO. 6

ESTIMATES FOR IRRIGATION WATER REQUIREMENTS

AT

LAM NAM OON

SAKON NAKHON, THAILAND

NOVEMBER, 1982

ISSUED BY

CENTER FOR RURAL DEVELOPMENT
LOUIS BERGER INTERNATIONAL, INC. U.S.A.
UNDER CONTRACT WITH MINISTRY OF
AGRICULTURE AND COOPERATIVES OF THE
KINGDOM OF THAILAND

WORK PERFORMED BY

ERROLL D. COLES

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FOREWORD

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1. Introduction:

This Technical Note #6 has been developed as a means of assisting the design and installation of a water delivery system for the Lam Nam Oon Integrated Rural Development project. The phrase "water delivery system" means, in this context,

> 'A method for allocating water to tertiary areas along a main canal into secondary canals and diverting water from the dam site into the main canal at the correct times so that the water reaches the diversion points in time and volume sufficient to enable farmer's to start the irrigation cycle'.

A "water delivery system' as defined above has three principal parts:

a. Analysis of climatic data:

   i. Determine potential evapotranspiration, using the Penman Method on daily basis for a period of at least 20 years of record.

   ii. Develop a predictive procedure for estimating evapotranspiration for three to five days in advance of time (this day plus three to five days).

   iii. Rainfall analysis on a daily basis and dry periods between rainfalls.

   iv. Develop predictive procedures for rainfall similar to (ii) above for evapotranspiration.

b. Crop Factors and Irrigation Water Requirements:

   i. Use existing crop coefficients (Kc, based on calculating growth curves of a number of crops and using a polynomial equation) initially. However, these should be corrected later - as referenced to local conditions; and Operations Research programs (for places like Pilot Area 2 at Lam Nam Oon) should start to collect such local data very early in the expansion of new irrigated cultivation.

   ii. Calculate stage-by-stage crop water requirements as the growing season progresses. The various efficiency factors, conveyance, diversion, field applications efficiency can be applied to area-specific conditions.

iii. By the foregoing means, the periodic Irrigation Water Requirements are obtained; and it is possible to calculate the timing and volume of water diversions from a dam or other structures 'downstream' from a dam.

c. The Conveyance System:

i. The rate – or speed – that water moves down the main canals, the secondary canals, and into the tertiary areas has to be calculated in relation to time. The difference between the calculated conveyance rates and the actual conveyance rates is known as the "lag time". This "lag time" also takes into account the maintenance conditions of the canals including: sediments accumulated, broken structures, leakages, farmer-built constructions like foot-bridges, etc. Accurate calculation of the "lag time" is important. In the first instance, it can be estimated from design drawings; but it is essential to start a program of measurements early so that actual "lag time", and rates of conveyance are known.

ii. Regulation of the various control structures is crucial because the Lam Nam Oon system is a "head over the outlet" operation through means of Constant Head Orifices (CHO's). This is different from 'even flow' systems and, as such, demands very thorough training and discipline of Zonemen, Water Masters, and Head Gate Operators. Instant and steady means of communication between such personnel and those setting the rates of flow must be a feature of the Lam Nam Oon system.

Technical Note #6 relates, in particular, to parts (a) and (b) as sketched above. This Note provides up-dated and essential 'first-cut' data drawn from rainfall analysis specific to the area. Similarly, it does the same for Crop Coefficients, Irrigation Efficiencies, and Field Crop Water Requirements.

It must be understood, though, that all of these data are drawn from what is past, what is designed, and what general facts related to the area signal. None are substitutes for a continuing effort, which every irrigation system should have, to collect current data showing 'real' conditions and applying that data to the management of the 'water delivery system'.

In this connection, the development and application of micro-computer-based 'water delivery system' management techniques provides a great opportunity for generally improving irrigation efficiencies. In the past, manual systems of management have been the only means of handling all the complex factors. Generally, the manual operation requires such great application of staff attention and management attention that little is done to collect and use up-dated data. Hence, manually operated systems are often managed with generalised data that may be five to ten years out of date. A micro-computer-based system, if properly programmed and operated, can radically reduce management time requirements. In turn, this can allow more time to be devoted to making certain that the data used to manage the system is current as well as scientifically predictive.

2. Approach Used in Technical Note #6

In this paper, as shown in the accompanying Tables, the Irrigation Water Requirements have been calculated for various crops grown on the soils of the Lam Nam Oon project. These calculations are based on the Penman method for estimating potential eventual evapotranspiration. In this connection, the mean monthly values used are based on 25 years of climatic data recorded at the Sakon Nakhon meteorological station.

It should be noted, parenthetically here, that these calculations of maximum water requirements for a range of crops have been applied by LBII and RID when designing the water delivery and drainage systems in Pilot Area 2 at Lam Nam Oon. This is commonly known as the "Lam Nam Oon" model.

During the period from 1969 to 1974 Engineering Consultants, Inc. (ECI) an American firm based in Denver, Colorado completed a number of studies in the Lam Nam Oon area. These included: feasibility, land classification, design, and drainage. In the course of these studies E.C.I. developed and used data for climatic analysis. The data used by them covered the period from 1940 to 1967 as gathered from the various recording stations on or in close proximity to the project area.

In preparing this Technical Note, the predictive data drawn from the E.C.I. analysis has been reviewed. It is noted that the E.C.I. specialists used the Thornthwaite Method for estimating potential evapotranspiration at Lam Nam Oon. This Method is not as a precise at that developed by Penman. Therefore, in Technical Note #6, the Penman Method is applied. Other than this one change, it has been found that the E.C.I. analysis of the climatic indices are relevant to the present situation.

However, as described below, additional features have been added when making the analysis presented in this Technical Note. For example, climatic data from 1952 up until 1981 is used in order to calculate a new set of indices required for estimating irrigation water requirements at Lam Nam Oon.

In order to clearly show the differences obtained from applying different methods to estimate potential evapotranspiration three methods are compared in Technical Note #6. These are the Jensen-Haise Method used by the Mekong Committee, the Thornthwaite Method used by E.C.I., and the Penman Method. All three are presented, using a Sakon Nakhon data base.

In Technical Note #6 the Effective Rainfall is estimated by means of a computer simulation methodology for a double rice crop (Wet and Dry Season) and for field crops using 25 years of records from the Sakon Nakhon meteorological station. A Hewlett-Packard 85 micro-computer, with appropriate programs, has been used to complete this exercise.

3. Brief Review - E.C.I. Climatic Data Analysis and Crop Water Estimates

The climatic indices for the Lam Nam Oon project area were initially analyised by E.C.I. to determine the hydrological data needed to design the dam, the reservoir capacity in relation to the irrigable area and the appurtenant structures. These data were obtained from 21 rainfall measuring stations within the project precincts. Five of these are recording stations while 16 are non-recording. The records cover a period from 1940 upto 1967. Some records go back to even earlier times. The observation stations are operated by the Meteorological Department or the R.I.D.

The E.C.I. analysis of the climatic data[1/], rainfall, wind, humidity, temperatures and day lengths, have all been found pertinent to the project LNO area.

The crop water requirements for field crops and rice were estimated by E.C.I. from the LNO project, area[2/]. As remarked earlier, the Thornthwaite Method was used to estimate the potential evapotranspiration based on data from the Sakon Nakhon station. Crop coefficients based on local data and other general values were used to estimate the crop water requirements.

Mean monthly rainfall (at a 50% chance of occurance) was used to estimate average field water requirements (irrigation water requirments, I.W.R.) based on records from 1951 to 1970 (for Sakon Nakhon).

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1. LNO Irrigation Project Feasibility Report. Volume II (a) E.C.I. June 1970.

2. LNO Irrigation Project Land Classification Report Vol. II. Appendices. Appendix A.

These data were shown in Figures A 14* and A 15[3/], for each month of the year.

Effective rainfall for rice was ambitiously based on a value of up to 200 mm per month, Figure A 13[3/] for rainfall at normal intensity. Thereafter, the effectiveness of rainfall diminishes very rapidly for rainfall of greater amounts. Effective rainfall for field crops was based on the assumption that water stored in the soil above 75 mm, rainfall would be ineffective, the method for calculating rainfall efficiency was shown.

Percolation rates for various soils in the project area were estimated to range, from 1 mm per day up to 4 mm., (see page 24)[4/].

Soil Group	Av. Percolation mm/day	Partial field applicaton efficiency Wet Season	Dry Season
M Ri 1	1	80	90
M Ri 2	1.5	80	90
M Ri 3	3	85	90
M Ri 4	3	90	90
M Ri 5	3	85	85
M Ri 6	4	90	90

Field application efficiencies for rice were shown to vary with the percolation rates, a low efficiency for low percolation and a high efficiency for high percolation rates.

The field application efficiencies for field crops were shown in the Table on page 26[5/] and range from 50% to 70% for various crops varying from season to season.

3/ Appendex A in Table A3[3/]

4/ Appendix A

5/ Appendix A

Irrigation soil management group (upland-type crops)	Field application efficiency, Ef, %					
	Field and specialty crops		Sugar cane and fruits		Vegetables and melons	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
MUi 1	60	65	65	70	55	60
MUi 2	55	60	60	65	60	65
MUi 3	50	55	55	60	50	55
MUi 4	65	70	70	75	55	60
MUi 5	65	70	70	75	55	60
MUi 6	50	55	55	60	45	50

Field water application rates were calculated using the equation.

N.W.R. = (est.av. period Etp. X Kt. X Km X K. X Kc)- (est. period, Re).

N.W.R. = net water requirement

est.av. period. ETp = estimated average periodic evapotranspiration (by Thornthwaite).

Kt & Km = temperature and humidity factors (see page 7)

Ke = crop growth factor

Kc = crop growth stage factor

est. period. Re = estimated period effective rainfall.

The value of N.W.R. divided by the field application efficiency gives the field water requirements (F.W.R).

"Maximum" field water was based on a 20% probability for high monthly potential evapotranspiration and 20% probability low monthly rainfall. (See Figures A 14 & A 15 6/)

The Appendix explains in some detail the methodology used in estimating water delivery rates and irrigation times. Some aspects of estimating field water requirements for land preparation of rice was given in section V, together with an equation for estimating the time needed for land preparation.

6/ Appendix A

4. Analysis of Recent Climatic Data

As observed in the earlier sections, the E.C.I. - gathered data only continues up to 1970. Nonetheless, within this limitation, it is relevant to current usages at Lam Nam Oon; and it has been helpful as a reference when further extending the data and analysis in this Technical Note #6.

The pertinent climatic data has been brought up to date in this Note - to 1980. This exercise shows that during the ten years period significant extremely high rainfall has occurred at the Lam Nam Oon area. As a result, this has raised the rainfall indices by a small margin. This may be seen by comparing the data in Figures A-14 and A-15, Annex A of the E.C.I. Report, with the data provided in the Note - Table 2.

a. Rainfall:

i. Review of Rainfall Records:

When preparing the analysis for this Note, the computer printouts for daily rainfall were obtained from four sources. The period covered was from 1952 up to 1980. The four sources included: the Hydrological Section, RID; the main Meteorology Station at Sakon Nakhon, and the subsidiary stations at Phanna Nikhom and Waritchaphum.

These computer printouts contained many entry errors; and they had to be corrected, slowly, by checking the original records at each station with the computer printouts. This was accomplished over a period of about three months.

The meteorological data needed to compute potential evapotranspiration using the Penman Method were obtained from the Meterological Department for daily values for the period 1961 up to 1977. The data base, on this, was derived from the daily observations of the Sakon Nakhon Meteorological Station.

All the data was carefully cross-checked to eliminate all transfer errors and mis-entrys. Mis-located points were corrected wherever possible. Some high rainfall values, which initially appeared to be incorrect, were cross-checked with adjacent stations and generally accepted; then, as valid.

ii. Annual Rainfall:

The annual rainfall for the three stations of Sakon Nakhon, Phanna Nikhom, and Waritchaphum for the years from 1954 to 1980 (corrected and adjusted) are shown in Table 1.

The data is shown for various cumulative frequencies (of non-exceedance) and return periods. These data are plotted on Figure 1.

The data follows a normal distribution. It demonstrates that the annual rainfall for the three localities is essentially similar in character with a slight increase in annual rainfall at Waritchaphum.

iii. Monthly Rainfall:

The Mean monthly rainfalls for the period 1952-1980 are plotted in Figure 2.

According to the IRRI potential cropping intensity classification system 4 the Lam Nam Oon project falls into Class III. This means that it has a monthly rainfall in excess of 200 mm. for 5 to 6.9 months. That indicates under Class III that two crops of early-maturing rice could be grown with the first crop direct-seeded on unpuddled soil.

At Lam Nam Oon there are certain soils and water storage factors which inhibit widespread application of the Class III meaning for that area. Nonetheless, such a Classification means that better use could be made of the rainfall even under irrigated conditions principally by planting shorter-maturing rice varieties than the present 150-day types.

iv. Bi-Monthly Rainfall:

The bi-monthly or half-monthly rainfall data for the stations is presented on Tables 3 and 4. These are plotted on Figure 3.

The bi-monthly rainfall follows a normal distribution and the cumulative frequencies and return periods are given in the Tables.

The effective rainfall values used in this Note to calculate irrigation water requirements at Lam Nam Oon are based on the bi-monthly rainfall rather than the monthly. This is because of the vary simple point that the normal water layer depth in paddies at Lam Nam Oon is about 100 mm and the approximate daily water requirements is 5 to 5 mm. Several factors contribute to this situation including the types of soils, drainage, and the presence of Perched and High Water Tables.

In any case, it can be assumed with confidence that the 100 mm. water layer will provide 14 to 16 days reserve water supply in the absence either of rainfall or irrigation water. Irrigation cycle times should be based upon this interval too. The foregoing refers to rice crops.

With reference to field crops, except in areas where excessive Perched or High Water Tables exist, a 7 to 10 day interval may be assumed to exist.

Both of these relate closely to a half-monthly rainfall return period.

b. Evapotranspiration (Et) Indices

Methods of estimating potential evapotranspiration can be divided into empirical approaches such as the Blaney-Criddle and Thornthwaite "formulas" which only require mean monthly temperatures. By contrast, more precise approaches such as the Penman Method use many meteorological parameters including: solar radiation, temperature, wind velocity, and vapor pressure.

The Penman Method is known to produce the most accurate results for short periods of a week based on daily observations. With continuously recorded data this method can produce accurate 6-hourly results, if needed. The Blaney-Criddle and the Thornthwaite Methods produce results accurate for long-term estimates of potential evapotranspiration of a month or more, estimates for shorter periods than this will be in error.

Another method of computation is that represented by the Jansen-Haise equation. This takes into account temperature and solar radiation. It produces sound monthly estimates; and it has been used by the Mekong Committee to estimate potential Et for Sakon Nakhon[5/].

i. Available Data

Daily records were obtained from the Meterological Department, Bangkok for the years 1961-1977 at Sakon Nakhon. These included daily temperatures, wind speed, daily sunshine duration, and relative humidity. Similar data was obtained for Udon Thani.

5/ Lower Mekong Hydrological Report, 1976, Mekong Committee, Bangkok

ii. Calculation of Potential Et

The Penman equations used are well known and can be found in any reference on agro-climatology.6/

The potential Et values were based on the mean monthly data for 17 years of record. The values are given in Table 7.

In Table 7, also, the Penman values are compared to those calculated with the Jansen-Haise Method and the Thornthwaite Method. As may be seen, the latter two result in values which are slightly higher than those used derived from application of the Penman Method. These Penman values were used to determine the design irrigation water requirements for Pilot Area 2.

It should be noted that an albedo value of 0.25 is used in the Penmen calculations. This is representative of reflectivity from a growing green crop.

c. Dependable Rainfall

This is defined as the amount of rainfall that will meet part of the irrigation water requirements. It is based on the mean daily rainfall for periods of half a month, this can be expressed as..

$$Rf = 1/15\ R\ (n,)T.$$

where

RF = daily rainfall, mm/day.

R(n,)T = rainfall for the n period for return period of T year.

In this case, n is for a period of half- a month and a return period of T = 2 years has been used to estimate the effective rainfall.

d. Effective Rainfall

Two methods can be used to estimate effective rainfall. the one method widely used has been discussed in the E.C.I. Report, Table A3, and is commonly known as the Technical Release 21" (T.R. 21) method.

6/ Drainage Principles and Applications, Volume III, Surveys and investigations, Chapter 19, determining evapotranspiration (I.W. Kijne) 1970, Publ. 16 Institute for Land Reclamation and Improvement

The second method is based on a computer simulation procedure including:

a. intensity and distribution of rainfall,

b. storage at the time the rain falls.

c. crop water use,

d. irrigation method, if applicable,

e. land form[7/]

f. drainage characteristics

The effective rainfall has been calculated for the Sakon Nakhon and other rainfall stations in the vacinity by the Mekong Committee[8/] for double cropped paddy rice,

a. the normal water layer is taken as 90 mm (STO).

b. an irrigation application of 45 mm is applied when the paddy level falls below 45 mm (STMIN).

c. The water level in the paddy is not allowed to raise above 135 mm. (STMAX).

And, the effective rainfall for a particular day is computed using the following procedure, where,

R	=	Rainfall on day n, in mm
Stn-1	=	Storage in paddy at the end of the previous day, in mm (or storage in the paddy at the beginning of day n,).
Stn	=	Storage in paddy at the end of day n, mm.
Am	=	crop water requirement for the month in which day n occurs, mm/day,
	=	(KCP X ETP + ORP)/N.

where,

KCP	=	crop coefficient
ETP	=	potential Et. mm.
ORP	=	Losses; percolation etc. mm.

7/ Land Classification Report. Vol. II, Appendix A. Dec. 1973, E.C.

8/ Lower Mekong Hydrological Report. OP.CIT

N = number of days per month, n.

Effective rainfall is calculated using the following procedure:-

The value of the paddy storage at the end of day n was tentatively calculated:

$$Stn = Stn-a + R. = Am,$$

ef. Stn was greater than STMAX (= 135 mm), the effective rainfall (ER) was taken to be,

$$ER = STMX + AM - Stn - 1.$$

and Stn taken to be equal to STMAX. If the value of Stn is less than or equal to STMAX then the effective rainfall for that day is equal to the rainfall R. If Stn is equal to the trial value of Stn or less than STMIW (= 45 mm) then Stn is set equal to STO (=90 mm) and irrigation has to be applied.

The above procedure can only be done on a computer. The mean values for double cropped rice are given n Table 5:

A similar procedure has been developed for field crops and these data are given in Table 5, too.

The T.R.21. method has been used to estimate the effective rainfall for the Sakon Nakhon data and these data are compared to the simulation data. The ratios of the mean monthly rainfall (T= 2 years) to the effective rainfall for each month compare fairly closely, for each method and for the field crops and for paddy.

The ratios have been used to estimate effective rainfall for the half-month periods in determining the design irrigation water requirements, in Pilot Area 2. These values are given in Table 6.

5. Soil Factors

Estimates of crop water requirements necessitates taking into account the soil factors. In the case of field crops the soil stress factor is in the early part of crop growth. The stress factor,

$$Ks = \log \left[\frac{1 + 100\ (1-Dp/Dt)}{\log\ (101)} \right]$$

where,

Ks = soil stress factor

Dp = soil water depletion expressed as a fraction

Dt = total available moisture content

The crop coefficient K is multiplied by Ks, the stress factor, the optimum depletion of soil water is an assumed constant fraction, Dp, of the total available water. The root zone expands with time from planting until a maximum depth is reached near maximum cover. The expanding root depth is assumed to increase linearly upto effective cover.

The value assumed for the soils and crops that may be grown on the project is based on the following data:

a. Mean Available Moisture Content*

i. Up to 3 bars.

1.21 mm/cm (Sx = 0.036)

ii. Up to 15 bars

1.61 mm/cm (Sc = 0.046)

Based on 61 observation for depths up to 150 cm.
(Sx is the standard diviation)

b. Bulk Density*

Mean B.D. = 1.622 gm/cm^2

(Sx = 0.153)

c. Porosity*

Mean P = 38.75%
(Sx = 6.005)

Using the 15 bar value and assuming 60% depletion,

$$Ks = \text{Log} \frac{1 + 100 \cdot (1 - .966/1.61)}{\text{Log } 101}$$

$$= 1.311$$

9/ Land Classification Report. E.C.I. Appendix D. Table 3b.

A value of 1.323 has been used in the calculations based on previous estimates of the stress factor.

The soil stress factor does not apply to rice.

A second factor is used to adjust the crop coefficient during the early part of crop growth before effective cover is reached. Following an application of water the evaporation (Es) from the soil surface will account for most of the water lost from the bare soil surface, before the plant shades the soil, this loss is adjusted by means of the following empirical equation.

$$Es = Ep(0.9 - (Ks, Kc).$$

Es = soil surface evaporation, mm/day

Ep = potential Et.

Ks = soil stress factor

Kc = Crop coefficient

6. Irrigation Efficiency

Although a wide range of efficiency factors have been used elsewhere, the design values used to estimate the design irrigation water requirements, are,

a. Tertiary Unit conveyance and distribution efficiency: 85%; Rice 90%.

b. Field application efficiencies

Rice:	
Field crops:	60%
Sugar cane:	80%
Maize:	75%

The irrigation water requirement is obtained by dividing the crop water requirement by total efficiency.

$$C.W.R. = \left[(Et \times Kc) + P\right] - Rf.$$

where,

C.W.R. = crop water requirements

Et = potential Et.

Kc = crop coefficient

P = percolation losses

Rf = effective rainfall

and,

I.W.R. = C.W.R/ec. X ef.

ec = conveyance efficiency

ef = field application efficiency

7. Crop Coefficients

Crop coefficients are used with potential Et to estimate crop water requirements and they are generally an empirical ratio of crop Et to some reference Et derived from experimental data. The time distribution of crop coefficients for a particular crop constitutes the crop curves (see Figures 4 to 10). These crop curves are derived from various sources[10/]. The polynomial coefficients in Tables 8 b and 8c. were derived by means of a computer program.

The crops selected are simply those grown on the Lam Nam Oon project at present and the planting dates appear to be those that the farmers use, based on observations. These arrays of crops in Figure 11 obviously constitute a crop sequence but not a formal cropping plan[11/]. The purpose of such a crop array is to provide an approximation of the highest irrigation water requirement for any crop or combination of crops grown at the same time. This would be the design irrigation water requirement. (I.W.R.)

8. Field Crop Irrigation Water Requirements

Irrigation water requirements have been calculated for those field crops given in Tables 8(a) to 8(h).

The calculation of daily I.W.R. for each half-monthly period is given in Table 9(a) to Table 16. These estimtes are plotted on Figure 12.

The calculation methodology is shown in the tables using all the parameters from in the preceeding sections.

The daily I.W.R. values are plotted in Figure 12.

10/ Wright J.L. Crop coefficients for Estimating daily crop evapotranspiration. A.S.A.E. 1982

11/ Jensen. M.E. Scheduling Irrigation uring climate-crop - soil data. Amev. Civil Engin. J. Irrigation and Drainage D.V. 96 (I.R.I.) 25-38, 1970.

9. Irrigation Water Requirements for Rice

The calculation methodology for dry season rice of a 130 days duration, is given in Table 9. The maximum I.W.R. occurs at the end of the land preparation period when three quarters of area has been transplanted. The required volume of water will be 0.26 l.p.s. per rai.

A similar calculation for dry season rice in Table 17, indicates that up to 0.48 lps/rai would be required when two thirds of the area had been transplanted. However, this delivery rate (I.W.R.) could be reduced by dividing the land preparation period into quarters instead of thirds.

a. Length of Land Preparation Period

The methodology[12/] of calculating the water required for land preparation is described in Appendix 1. The basis of these calculations assume that land preparation extends over a period of 45 days. There is no way of establishing the validity of the length of this period under irrigated conditions at this stage and a first approximation of 45 days has been used - the period may well be as long as 60 days or as short as 30 days. However, a shorter period will need a greater volume of water.

b. Incremental Periods

The incremental periods, sub-divisions of the total time for land preparation, are arbitarily chosen. They can be, thirds, quarters, fifths or sixths. However, design values are taken at third or fourth intervals. Less water will be required for smaller incremental periods. For these calculations thirds were used for dry season rice and quarters for wet season rice.

c. Water for Land Preparation

The depth of water required for land preparation has been taken at 250 mm; saturation water at 140 mm; establishing a water layer, 100 mm deep and 10 mm loss to percolation for the period.

d. Nursery water requirements

Nominally, one unit area of nursery is required for 15 to 20 units of paddy. The total water required for the nursery is from 400 to 600 mm over a 30 to 40 day period. This amount of water is not included in the I.W.R. estimates. Though the nursery water requirements are included in overall water delivery estimates they are excluded from the design estimates.

12/ V.D. Gook and G. Zijlstra Irrigation requirements for double-cropping of lowland rice in Malaya. Publ. 14. int. inst. reclamation and improvement, Wageningen, Netherlands.

e. Percolation Rates

Percolation rates for design purposes are assumed to be 1.0 mm per day for the soils in Pilot Area 2; precolation rates for various soil groups are given in a preceding section.

In conclusion, the design I.W.R. for dry and wet season rice do not vary from estimates for areas with a similar climate and a design value of 0.25 lps/rai could be safely used for estimating capacity of channels and structures.

Table No. 1

Annual Rainfall for Three Stations

Cumulative Probability	Return Period in years	Sakon Nakhon 1954 - 1980	Phanna Nikhom 1954 - 1980	Waritchaphum 1954 - 1980
.01	1	799.8	851.4	1193.8
.50	2	1485.7	1469.9	1559.5
.67	3	1682.9	1647.9	1685.1
.80	5	1732.9	1693.0	1799.4
.90	10	1862.5	1809.9	1925.1
.96	25	2000.9	1934.7	2059.3
.98	50	2089.2	2014.4	2145.0

NO 340-PS 90 DIETZGEN GRAPH PAPER
PROBABILITY X 90 DIVISIONS

EUGENE DIETZGEN CO.
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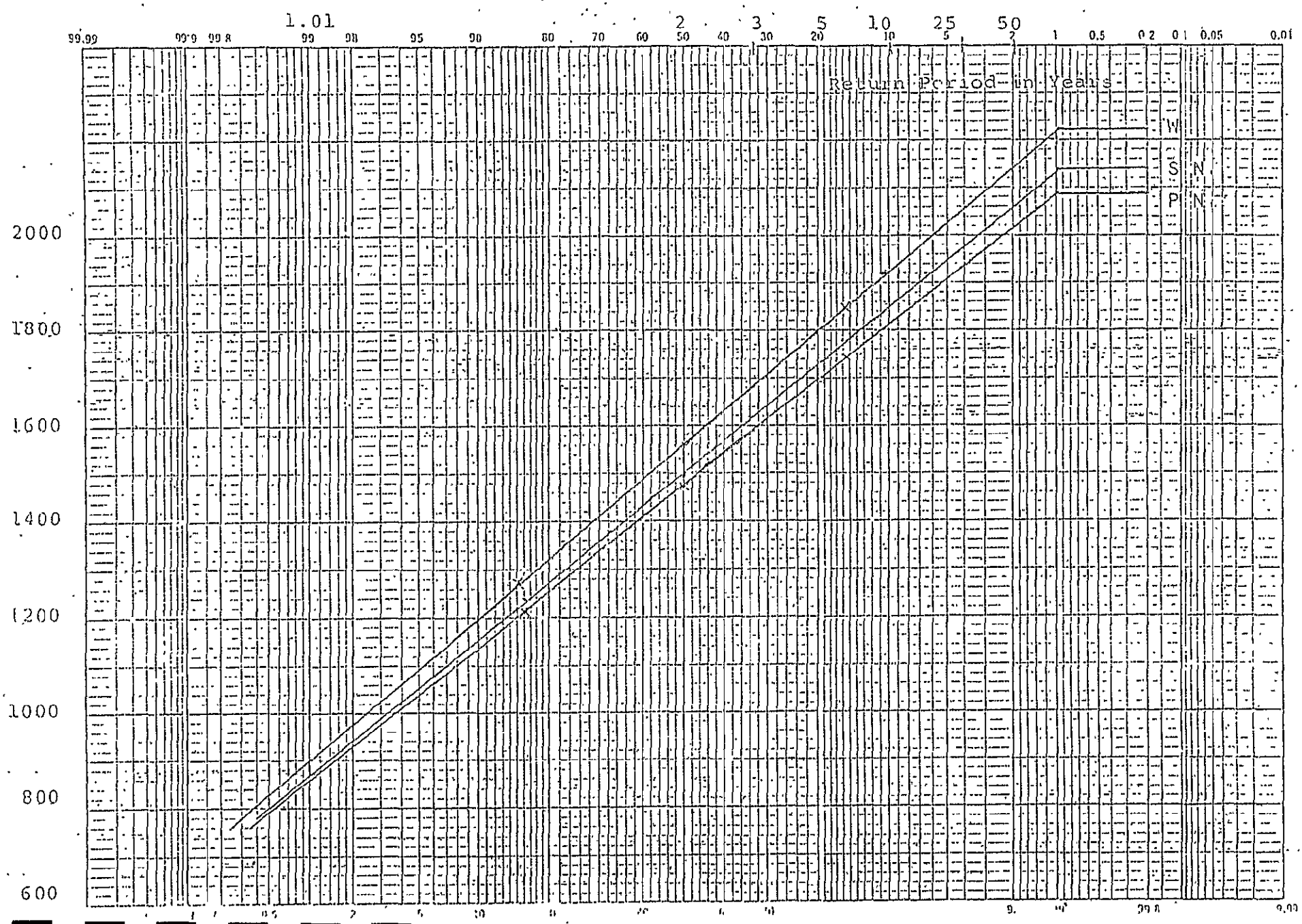
Figure 1



K+E 1 YEAR BY MONTHS X 100 DIVISIONS
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1954 - 1980

Figure 2

Sakon Nakhon

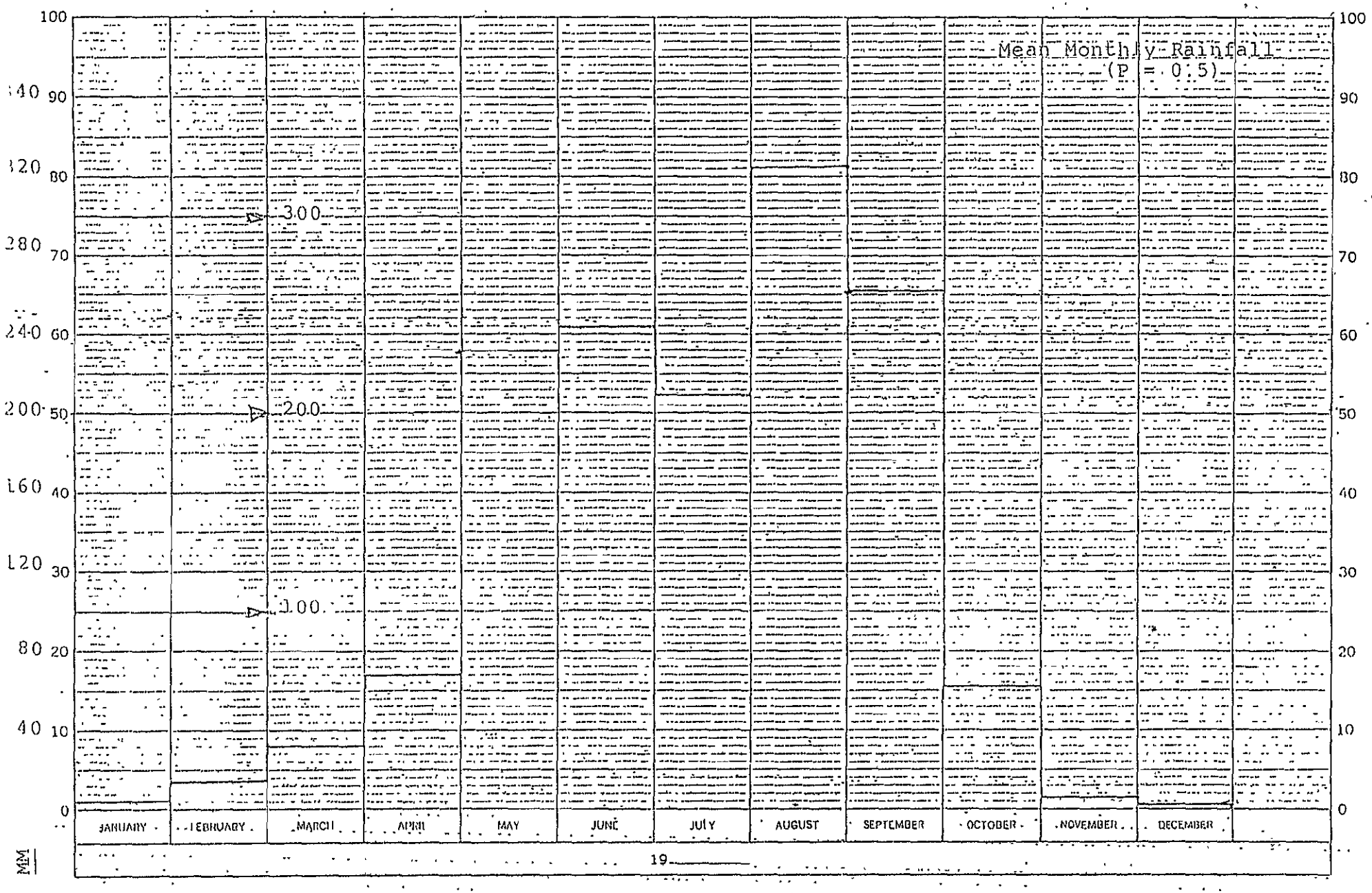

Table No. 2

Sakon Nakhon 1954 - 1980 (27 years)

Half Monthly (15 day) Rainfall

MONTHS

Probability	Return Period in years	Jan. 1	Jan. 2	Feb. 1	Feb. 2	March 1	March 2	April 1	April 2	May 1	May 2	June 1	June 2	July 1	July 2	Aug. 1	Aug. 2	Sept. 1	Sept. 2	Oct. 1	Oct. 2	Nov. 1	Nov. 2	Dec. 1	Dec. 2
.01	1	-	-	-	-	-	-	-	-	-	44.70	50.9	21.9	23.1	22.7	32.1	-	36.0	28.7	27.5	-	-	-	-	-
.50	2	.97	3.57	6.09	7.20	13.33	22.19	33.75	43.40	93.98	138.75	134.1	109.5	117.5	91.7	152.1	171.2	166.2	86.3	39.1	22.0	5.6	-	-	1.2
.67	3	2.92	9.61	14.35	19.45	24.42	37.55	54.53	62.90	135.72	187.98	177.7	155.3	166.8	128.2	214.8	264.2	234.4	131.6	73.9	53.8	14.3	-	-	5.5
.80	5	3.41	11.21	16.45	22.56	27.23	41.70	59.80	67.85	146.28	200.47	188.7	166.9	179.4	137.4	230.8	287.8	251.7	140.6	82.7	57.6	16.5	-	-	10.4
.90	10	4.69	15.10	28.87	30.60	34.51	51.92	73.44	80.66	173.72	232.8	217.3	197.0	211.8	161.3	272.0	348.9	296.4	163.8	105.6	67.3	22.2	-	-	16.4
.96	25	6.06	19.34	27.67	39.16	49.29	62.84	88.02	94.34	203.01	267.3	247.9	229.2	246.4	186.7	316.1	414.2	344.2	188.6	130.0	77.6	28.3	-	-	24.1
.98	50	6.94	22.04	31.37	44.67	47.26	69.81	97.32	103.08	221.70	289.4	267.4	249.7	268.6	202.9	344.2	455.8	374.7	204.5	145.6	84.2	32.2	-	-	29.8

K+E 1 YEAR BY MONTHS X 100 DIVISIONS
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1954 - 1980

Figure 3

Sakon Nakhon

Mean Half-monthly Rainfall (P = 0.5)

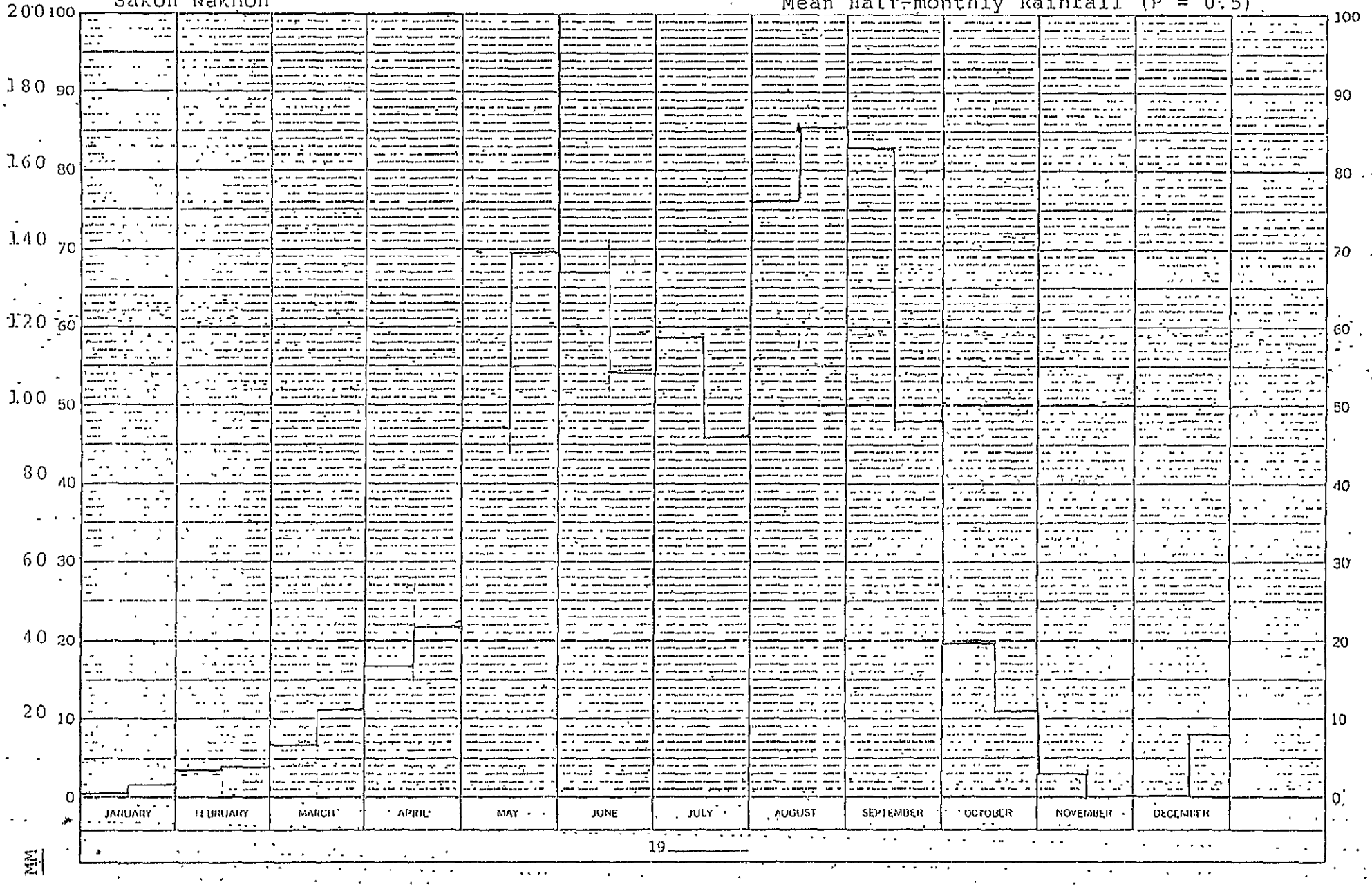


Table No. 3

Phanna Nikhom 1954 - 1980

Half-monthly (15 day) Rainfall

Cumulative Probability	Return Period in years	MONTHS																							
		Jan.		Feb.		March		April		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
.01	1	-	-	-	-	-	-	-	-	1.7	34.5	43.3	29.2	12.1	46.3	26.1	45.9	58.4	16.4	-	-	-	-	-	-
.50	2	0.61	4.7	4.3	8.9	16.1	24.6	27.3	38.8	93.1	136.2	137.8	115.1	117.7	116.8	156.2	162.2	149.9	95.8	38.3	16.4	16.4	-	-	-
.67	3	2.2	13.1	10.9	18.6	37.9	44.9	44.2	59.9	140.9	189.5	187.3	160.1	153.9	140.9	200.9	199.5	189.3	123.1	54.8	26.4	22.2	-	-	-
.80	5	2.58	15.2	12.5	21.1	43.4	50.1	48.5	65.3	153.0	203.0	199.8	171.5	186.9	163.0	241.6	235.2	225.0	147.9	69.9	35.4	35.5	-	-	-
.90	10	3.62	20.6	16.9	27.6	57.7	63.5	59.6	79.2	184.4	238.0	232.3	201.1	223.2	187.2	286.3	274.5	264.3	175.3	86.4	45.3	50.1	-	-	-
.96	25	4.72	26.5	21.5	34.4	72.9	77.8	71.4	93.9	217.9	275.4	267.0	232.7	261.9	213.1	334.1	316.5	306.3	204.5	104.1	55.9	65.7	-	-	-
.98	50	5.43	30.2	24.4	38.8	82.6	86.9	78.9	103.4	239.4	299.2	289.2	252.8	286.7	229.6	364.6	343.3	333.1	223.1	115.4		75.6	-	-	

Table No. 4

Waritchaphum 1955 - 1980 (Incomplete Array)
Half-monthly (15 day) Rainfall

MONTHS

Probability/ Return Period in years	Jan. 1	Jan. 2	Feb. 1	Feb. 2	March 1	March 2	April 1	April 2	May 1	May 2	June 1	June 2	July 1	July 2	Aug. 1	Aug. 2	Sept. 1	Sept. 2	Oct. 1	Oct. 2	Nov. 1	Nov. 2	Dec. 1	Dec. 2
.1	-	-	-	-	-	-	7.0	6.5	-	27.8	80.0	8.4	16.1	19.5	16.6	17.5	54.8	15.9	-	-	-	-	-	-
2	4.2	4.3	5.7	13.1	19.4	32.6	40.3	55.6	77.6	144.2	158.6	117.5	108.5	113.0	152.5	135.5	179.4	76.9	37.3	27.9	-	-	-	-
3	12.2	8.9	11.8	23.1	30.7	45.9	51.7	72.5	104.7	184.2	185.0	155.1	151.3	145.1	199.3	186.4	222.2	97.9	60.8	46.6	-	-	-	-
5	19.4	12.9	17.3	32.2	41.0	58.0	62.1	87.9	129.3	220.6	210.2	189.2	190.3	174.4	241.7	243.2	261.2	116.9	82.1	63.6	-	-	-	-
10	27.4	17.5	23.3	42.2	52.3	71.3	73.5	104.8	156.4	260.6	237.2	226.7	233.1	206.5	288.5	314.5	303.9	137.9	105.6	82.3	-	-	-	-
25	35.9	22.4	29.7	52.9	64.4	85.6	85.7	122.8	185.3	303.3	266.1	266.8	278.8	240.8	338.4	404.6	349.7	160.3	130.6	102.3	-	-	-	-
50	41.4	25.5	33.8	59.7	72.1	94.6	93.5	134.3	203.8	330.6	284.5	292.4	308.1	262.8	370.2	471.5	378.9	174.6	146.6	115.0	-	-	-	-

Table No. 5

Effective Rainfall

A Comparison of various Methods of Estimating Effective Rainfall for the Sakon Nakhon Data

Method	Month											
	Jan.	Feb.	Mar.	Apl.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
T.R. 21 Method												
Mean Monthly Rainfall	5	14	36	77	233	243	209	323	263	61	6	3
Effective Rainfall	3	19	23	48	132	111	108	109	101	38	5	–
Ratio E.R./R	.56	.69	.65	.62	.56	.45	.52	.34	.38	.62	.80	1.0
Simulation Method												
Diversified Cropping												
Mean Monthly Rainfall	7	21	42	74	225	273	119	290	284	70	6	3
Effective Rainfall	7	14	38	61	115	93	105	141	119	50	5	3
Ratio E.R./R	1.0	.67	.90	.82	.50	.34	.53	.49	.42	.70	1.0	1.0
Double Paddy Cropping												
Mean Monthly Rainfall	7	21	42	74	226	273	199	290	284	70	6	3
Effective Rainfall	7	21	41	74	124	140	163	190	156	58	6	3
Ratio E.R./R	1.0	1.0	.98	1.0	.55	.51	.82	.66	.55	.83	1.0	1.0

Table No. 6

Effective Rainfall for 2 and 10 Year Return Period for 15 day Rainfall (equal to or greater than) for Sakon Nakhon

ameters	Jan. 1	Jan. 2	Feb. 1	Feb. 2	March 1	March 2	April 1	April 2	May 1	May 2	June 1	June 2	July 1	July 2	Aug. 1	Aug. 2	Sept. 1	Sept. 2	Oct. 1	Oct. 2	Nov. 1	Nov. 2	Dec. 1	Dec. 2
:o																								
nfall ficiency ctor	1.0	1.0	1.00	1.00	.98	.98	1.00	1.00	.55	.55	.51	.51	.82	.82	.66	.66	.55	.55	.83	.83	1.00	1.00	1.00	1.00
year turn riod	0.97	3.57	6.09	7.20	13.0	21.8	33.8	43.4	51.7	76.3	60.4	55.6	96.4	75.2	100.4	112.9	91.4	52.9	32.5	18.3	5.6	-	-	1.2
year turn riod	4.96	15.1	28.9	30.6	33.8	50.9	73.4	80.7	95.5	128.0	110.8	100.5	173.7	132.3	176.5	230.3	163.0	90.1	87.6	55.9	22.2	-	-	16.4
eld Crops:																								
nfall ficiency ctor	1.00	1.00	.67	.67	.90	.90	.82	.82	.50	.50	.34	.34	.53	.53	.49	.49	.42	.42	.70	.70	1.0	1.0	1.00	1.00
year turn riod	.97	3.57	4.1	4.8	11.9	19.9	61.5	35.6	46.9	69.4	45.6	37.2	62.3	48.6	74.5	83.9	69.8	40.4	27.4	15.4	5.6	-	-	1.2
Year turn riod	4.69	15.1	19.4	20.5	31.1	46.7	60.2	66.1	86.9	116.4	73.9	66.9	112.3	85.5	133.3	170.9	124.5	68.8	73.9	47.1	22.2	-	-	16.4

Rainfall data taken from Table No. 2.

Table No. 7

A Comparison of Potential Evapotranspiration Determinations at Sakon Nakhon and Udon Thani using Penman, Jensen - Haise, and Thornthwaite Methods.

Locality / Method	Months - mm/day											
	Jan.	Feb.	Mar.	Apl.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1. Sakon Nakhon												
Penman	3.38	4.18	4.85	5.35	4.81	4.47	4.43	3.97	3.79	4.24	3.76	3.25
Jensen-Haise*	4.16	4.89	5.81	6.53	6.09	5.37	5.48	5.06	5.07	5.32	4.70	4.06
Thornthwaite**	2.16	3.50	5.48	6.30	5.55	5.13	5.09	4.61	4.40	4.35	3.30	2.35
2. Udon Thani												
Penman	2.97	3.65	4.58	4.97	4.66	4.30	4.24	3.84	3.76	3.87	3.33	2.78
Jensen-Haise*	4.16	5.04	6.03	6.80	6.52	5.90	5.81	5.57	5.10	5.32	4.67	4.03

* Hydrological Report. Mekong Committee.

** Land Classification Report (E.C.I.) Vol. II. Appendix A. pp. 8. Table 2 A.

Table No. 8(a)

Crop Data

Sugar Cane

Growing Period: 365 + days

Planting day: Dec./Jan.

Effective Cover: 100 days

Effective rooting depth 100 cm

Stage	Days	% Time	Kc
	0		
1	10	10	.46
	20	20	.53
	30	30	.59
2	40	40	.67
	50	50	.74
2	60	60	.80
	70	70	.90
2	80	80	.94
	90	90	.965
	100	100	1.00
3	120	100	1.04
3	151	100	1.00
3	181	100	1.00
4	212	75	.75
4	243	75	.75
5	273	50	.50
5	304	50	.50
H	334	20	.20
H	365	20	.20

H = Drying off - pre-harvesting.

Table No. 6

Effective Rainfall for 2 and 10 Year Return Period for 15 day Rainfall (equal to or greater than) for Sakon Nakhon

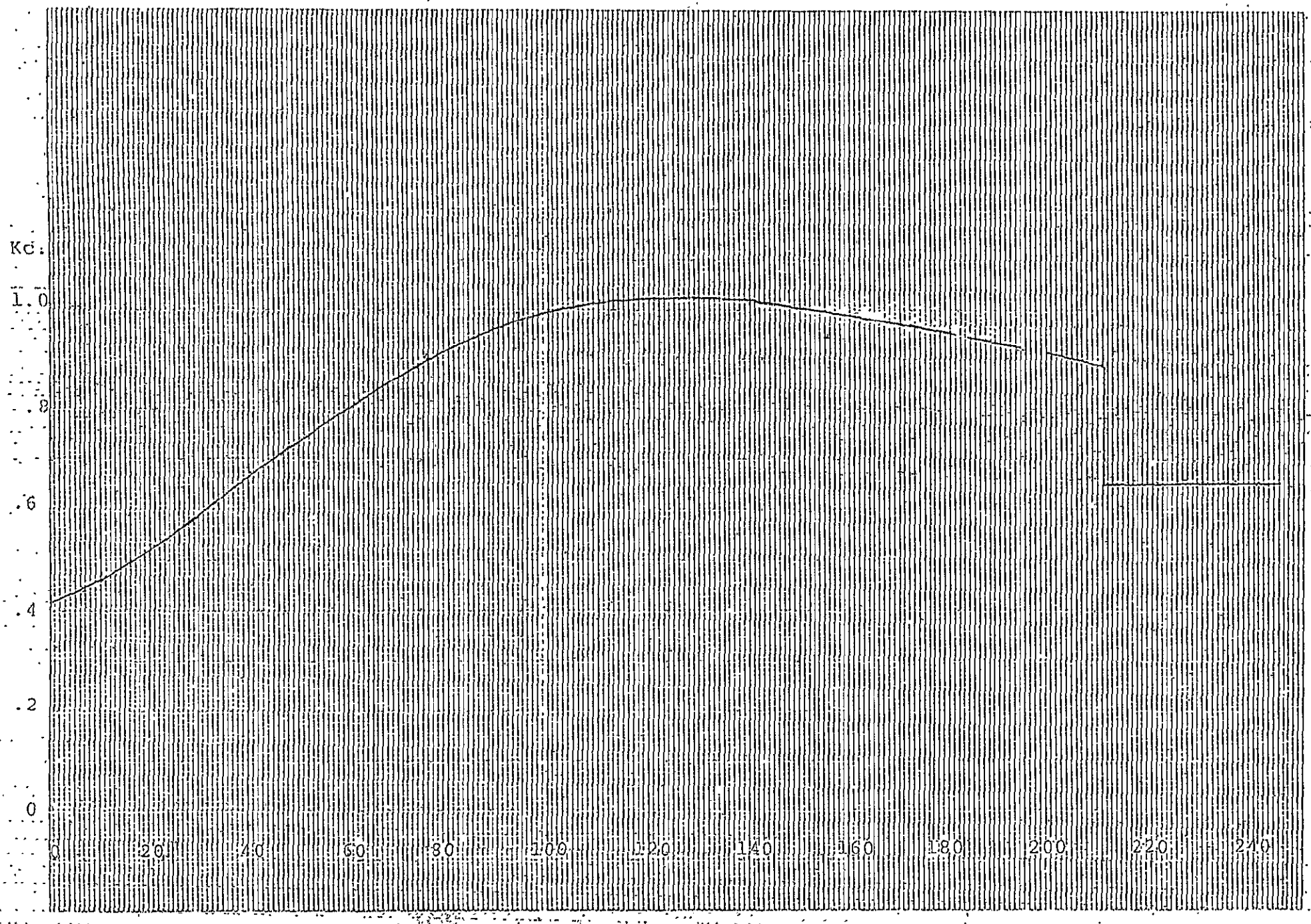
MONTH
MM

ameters	Jan. 1	Jan. 2	Feb. 1	Feb. 2	March 1	March 2	April 1	April 2	May 1	May 2	June 1	June 2	July 1	July 2	Aug. 1	Aug. 2	Sept. 1	Sept. 2	Oct. 1	Oct. 2	Nov. 1	Nov. 2	Dec. 1	Dec. 2
e																								
infall ficiency ctor	1.0	1.0	1.00	1.00	.98	.98	1.00	1.00	.55	.55	.51	.51	.82	.82	.66	.66	.55	.55	.83	.83	1.00	1.00	1.00	1.0
ear turn riod	0.97	3.57	6.09	7.20	13.0	21.8	33.8	43.4	51.7	76.3	60.4	55.6	96.4	75.2	100.4	112.9	91.4	52.9	32.5	18.3	5.6	-	-	1.7
year turn riod	4.96	15.1	28.9	30.6	33.8	50.9	73.4	80.7	95.5	128.0	110.8	100.5	173.7	132.3	176.5	230.3	163.0	90.1	87.6	55.9	22.2	-	-	16.4
eld Crops																								
infall ficiency ctor	1.00	1.00	.67	.67	.90	.90	.82	.82	.50	.50	.34	.34	.53	.53	.49	.49	.42	.42	.70	.70	1.0	1.0	1.00	1.0
year turn riod	.97	3.57	4.1	4.8	11.9	19.9	61.5	35.6	46.9	69.4	45.6	37.2	62.3	48.6	74.5	83.9	69.8	40.4	27.4	15.4	5.6	-	-	1.7
Year turn riod	4.69	15.1	19.4	20.5	31.1	46.7	60.2	66.1	86.9	116.4	73.9	66.9	112.3	85.5	133.3	170.9	124.5	68.8	73.9	47.1	22.2	-	-	16.4

Rainfall data taken from Table No. 2.

Crop Coefficient for Sugar Cane

Figure 4



Sugar Cane (continued)

Figure 4 (c)

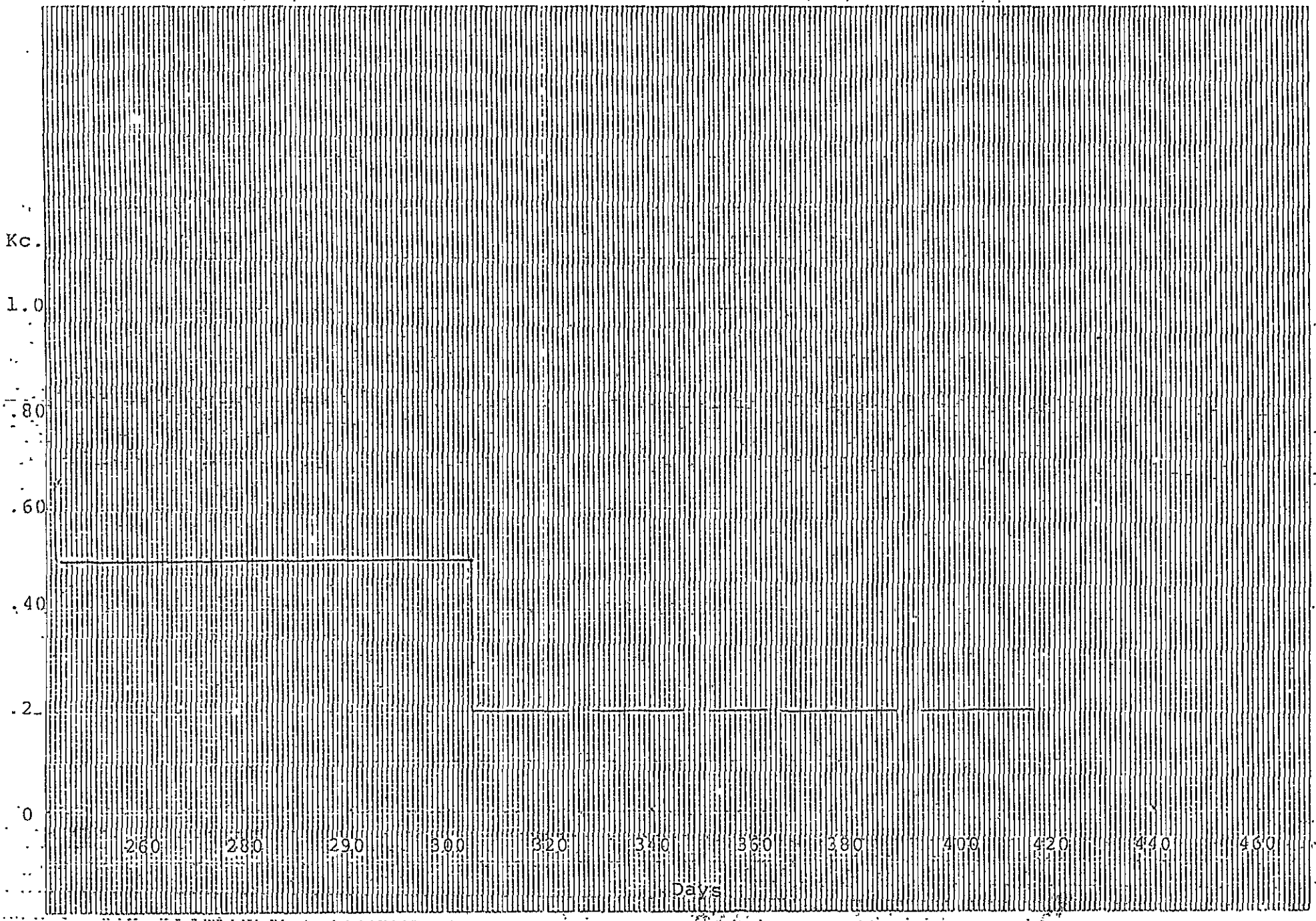


Table No. 8b

Crop Data

Groundnuts

Growing period	100 - 110 days
Planting date	Nov./Dec. - Dec./Jan.
Effective cover	50 days
Effective rooting depth	30 - 40 cm

Crop Coefficients Kc.

1. Before effective cover

A = - 1.353
B = 2.562
C = - .3532
D = .212

2. After effective cover

A = .165 E - 8
B = - .2644 E - 7
C = - 112 E - 6
D = 1.05.

%	Kc.	Days	Days	Kc.
10	.201	5	50	1.043
20	.233	10	55	1.023
30	.300	15	60	.986
40	.394	20	65	.942
50	.507	25	70	.882
60	.603	30	75	.809
70	.756	35	80	.723
80	.876	40	85	.624
90	.983	45	90	.511
100	1.068	50	95	.386
			100	.247
			110	.095

(100% = 50 days)

Crop Coefficient for Groundnut

Figure 5

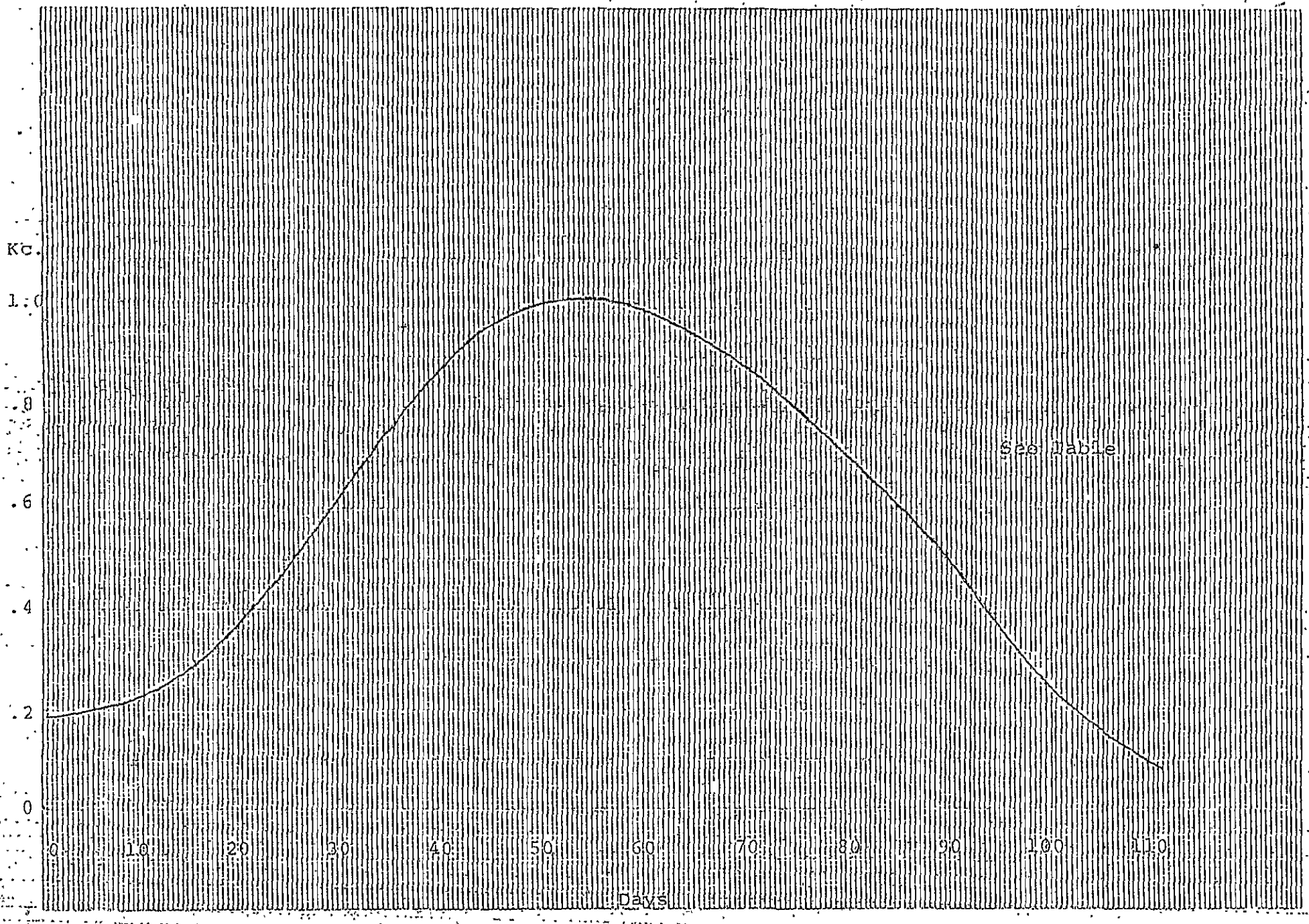


Table No. 8c

Crop Data

Maize (Green Crop)

Growing Period:	75 - 90 days
Planting dates:	Nov./Dec., due 1 Dec.
Effective cover:	45 day after planting
Effective Rooting Depth:	60-80 cm.

Crop coeffiecient Kc.

1. Before effective cover

A = - 1.583 (%)
B = 2.756
C = - .4276
D = .213

2. After effective cover.

A = .275E-8 (days)
B = - 4688E-7
C = .01195
D = .915

%	Kc.	days
10	.196	0
20	.225	5
30	.290	10
40	.382	15
50	.490	20
60	.607	25
70	.721	30
80	.824	35
90	.907	40
100	.958	45

days	Kc.
45	.958
50	.963
55	.990
60	.998
65	.989
70	.967
75	.926
80	.877
85	.819
90	.754

(100% = 45 days)

Crop Coefficient for Maize

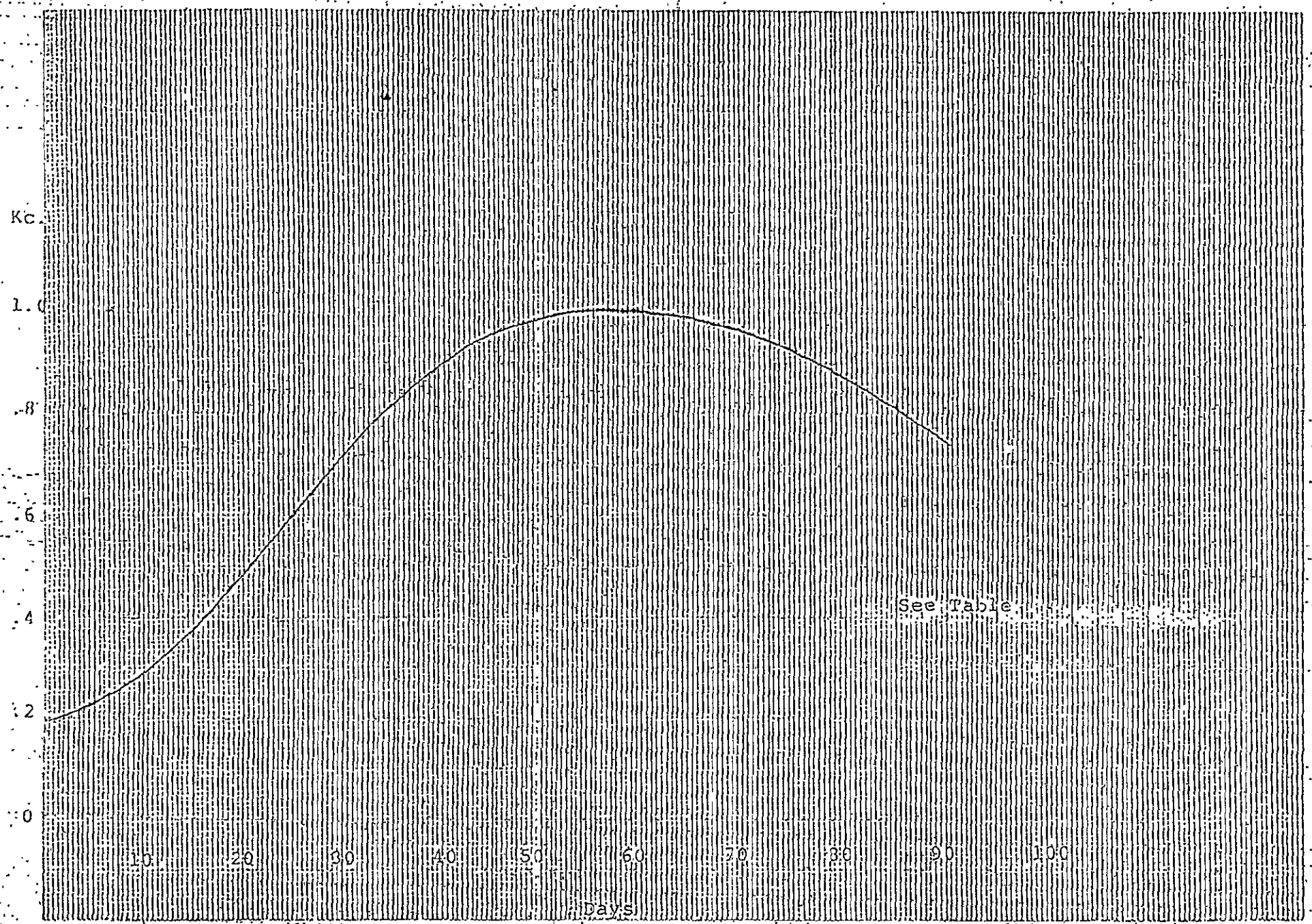


Table No. 8d

Crop Data

Bean (grain) Mung beans

Growing period:	80/90 days
Planting date:	Mid January
Effective cover:	40 days
Effective Rooting depth:	40 - 60 cm.

Crop Coefficient

%	days	Kc
10	10	.27
20	20	.46
30	30	.71
40	40	.90
50	50	1.00
60	60	.99
70	70	.87
80	80	.69
90	90	.48
100	100	.295

Crop Coefficient for Beans

Figure 7

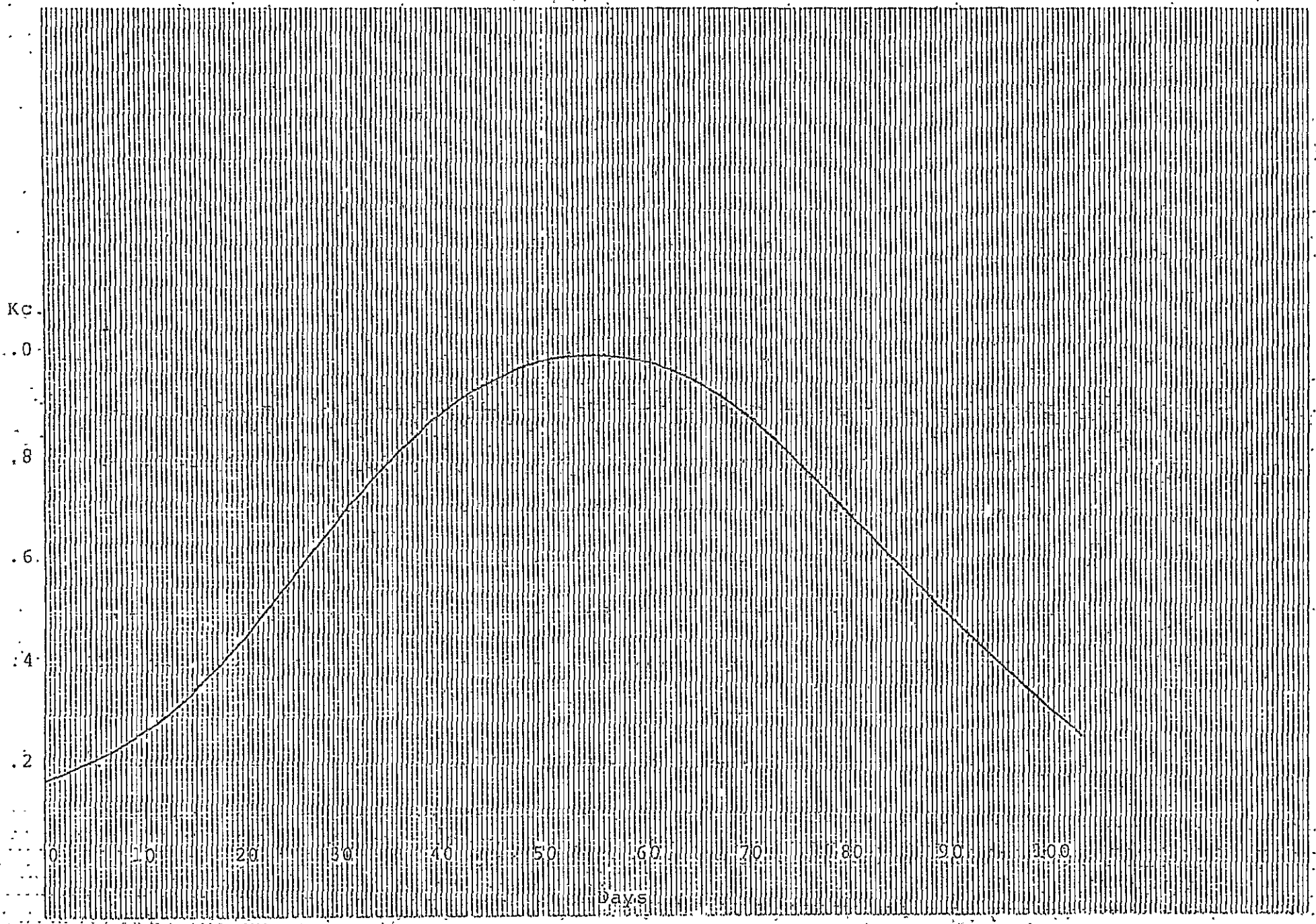


Table No. 8e

Crop Data

Vegetables:

Growing Period: 60 to 90 days (Use 90)
Planting dates:
Effective cover: 45/50 days
Effective rooting depth: 30 to 60 cms.

Crop coefficients:

%	days	Kc
10	10	.30
20	20	.54
30	30	.76
40	40	.89
50	50	.96
60	60	.96
70	70	.93
80	80	.79
90	90	.58
100	100	.28

Crop Coefficient for Vegetables

Figure 8

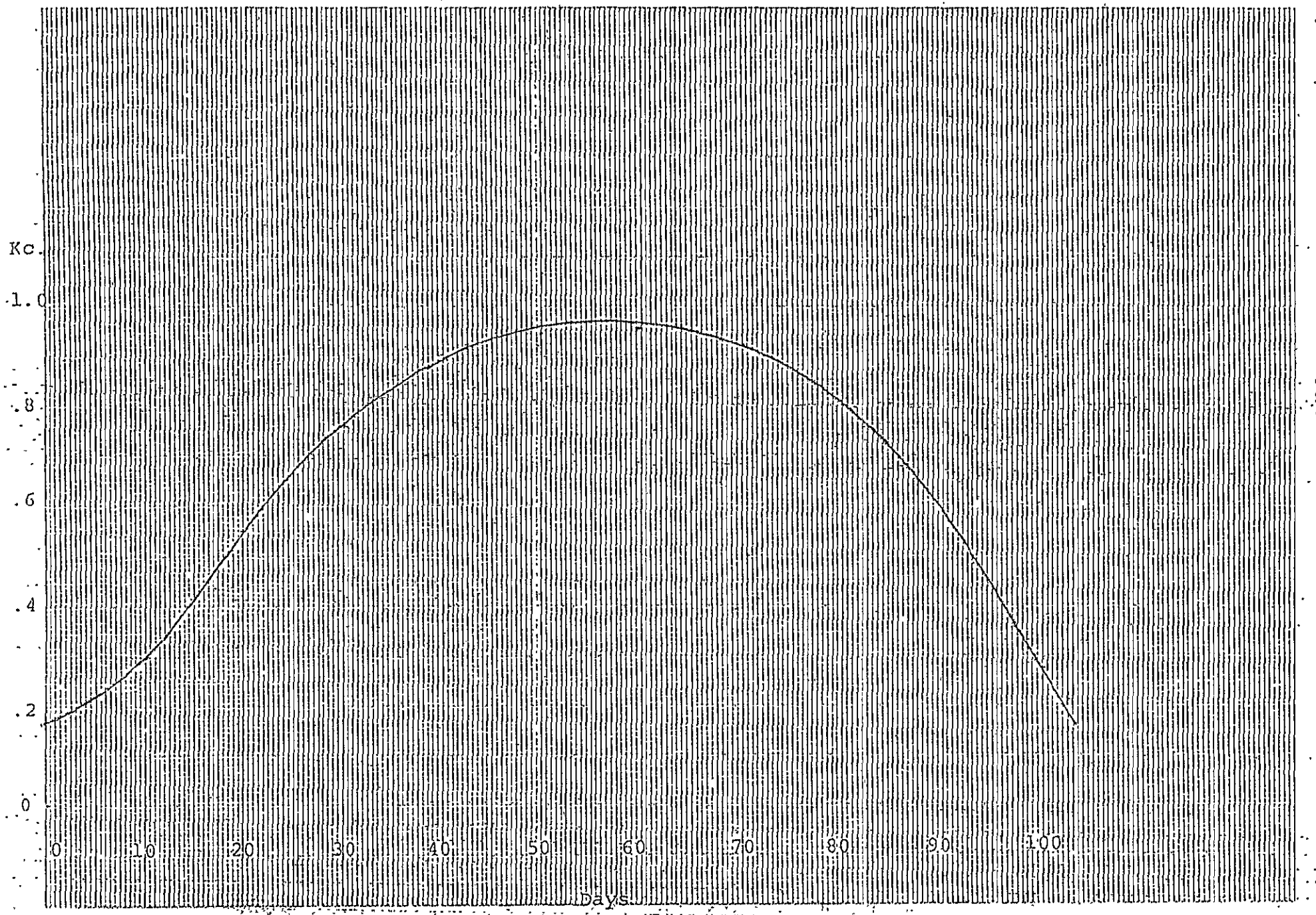


Table No. 8f

Crop Data

Melons

Growing period:	100/120 days
Planting dates:	Dec./Jan.
Effective cover:	50 days
Effective Rooting depth:	60 to 80 cm.

Crop Coefficient

%	days	Kc
10	10	.30
20	20	.44
30	30	.66
40	40	.885
50	50	1.00
60	60	1.01
70	70	.94
80	80	.89
90	90	.84
100	100	.80

Crop Coefficients for Melons

Figure 9

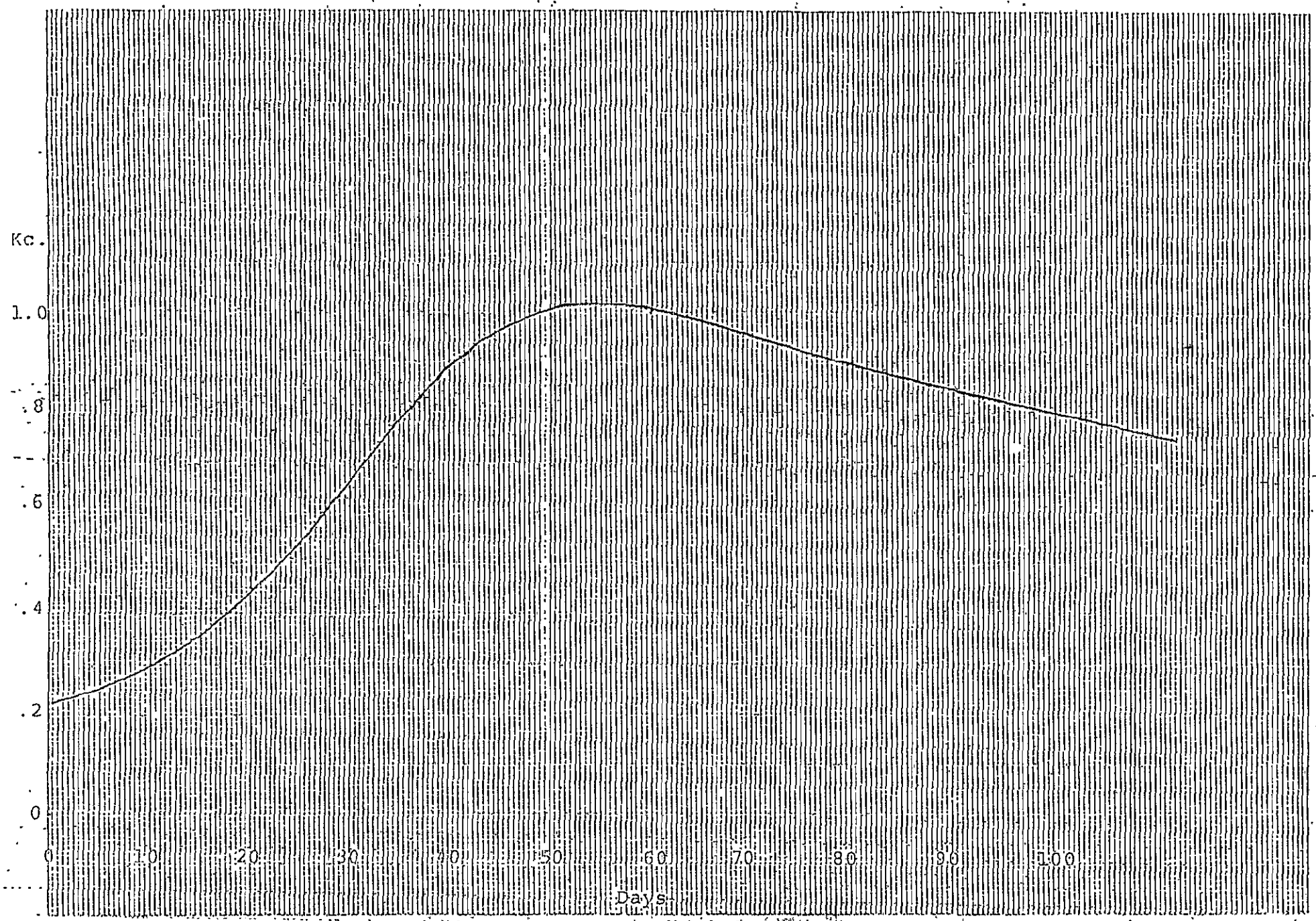


Table No. 8g

Crop Data

Rice

Growing Period:	120/130/150 days
Planting dates:	variable
Effective cover:	–
Effective rooting depth:	paddy, 70-90 cm

Growing Period-days	Crop Factor, Kc
0	0
15	1.02
30	1.20
45	1.32
60	1.40
75	1.35
90	1.24
105	1.12
120	0.95

Table No. 8h

Factors for Converting 120 day
Crop Coeffecients to other growing periods

Percent of Time %	120 day		130 day		150 day	
	day	Kc	day	Kc	day	Kc
10	12	1.05	13	1.05	15	1.05
20	24	1.12	26	1.12	30	1.12
30	36	1.27	39	1.27	45	1.27
40	48	1.36	52	1.36	60	1.36
50	60	1.40	65	1.40	75	1.40
60	72	1.38	78	1.38	90	1.38
70	84	1.29	91	1.29	105	1.29
80	96	1.195	104	1.195	120	1.195
90	108	1.09	117	1.09	135	1.09
100	120	.95	130	.95	150	.95

Crop Coefficient for Rice

Figure 10

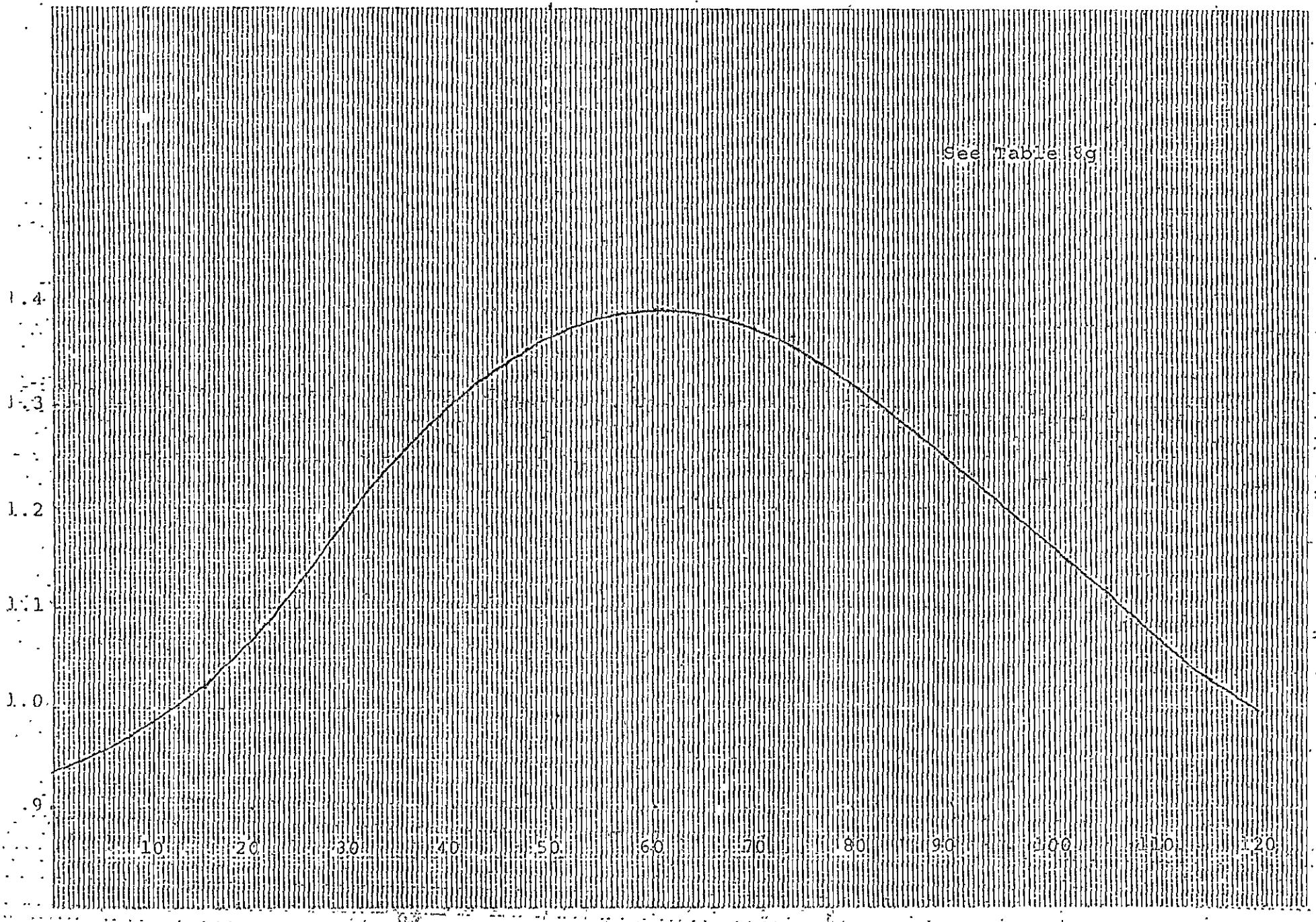
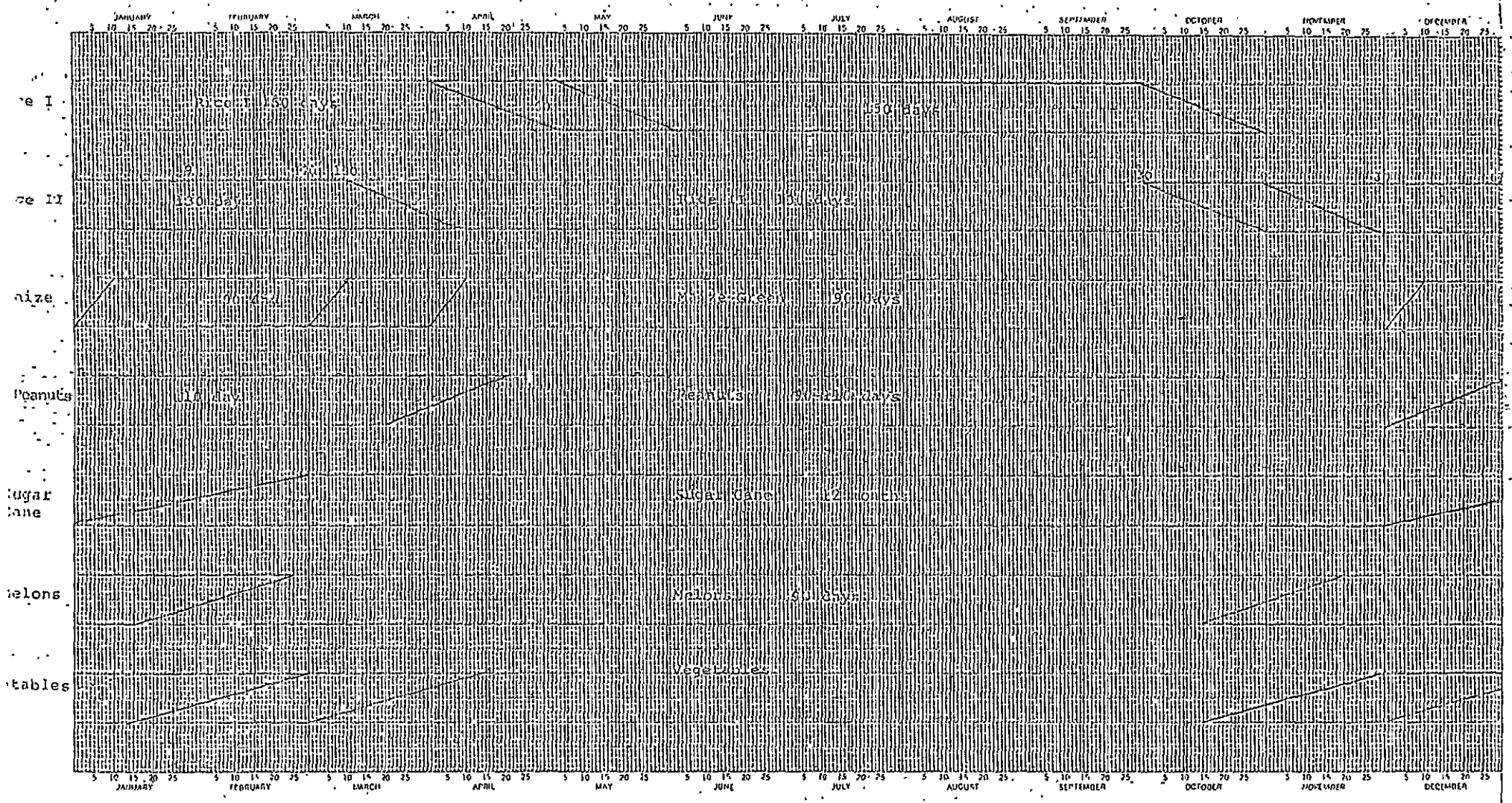


Figure 11

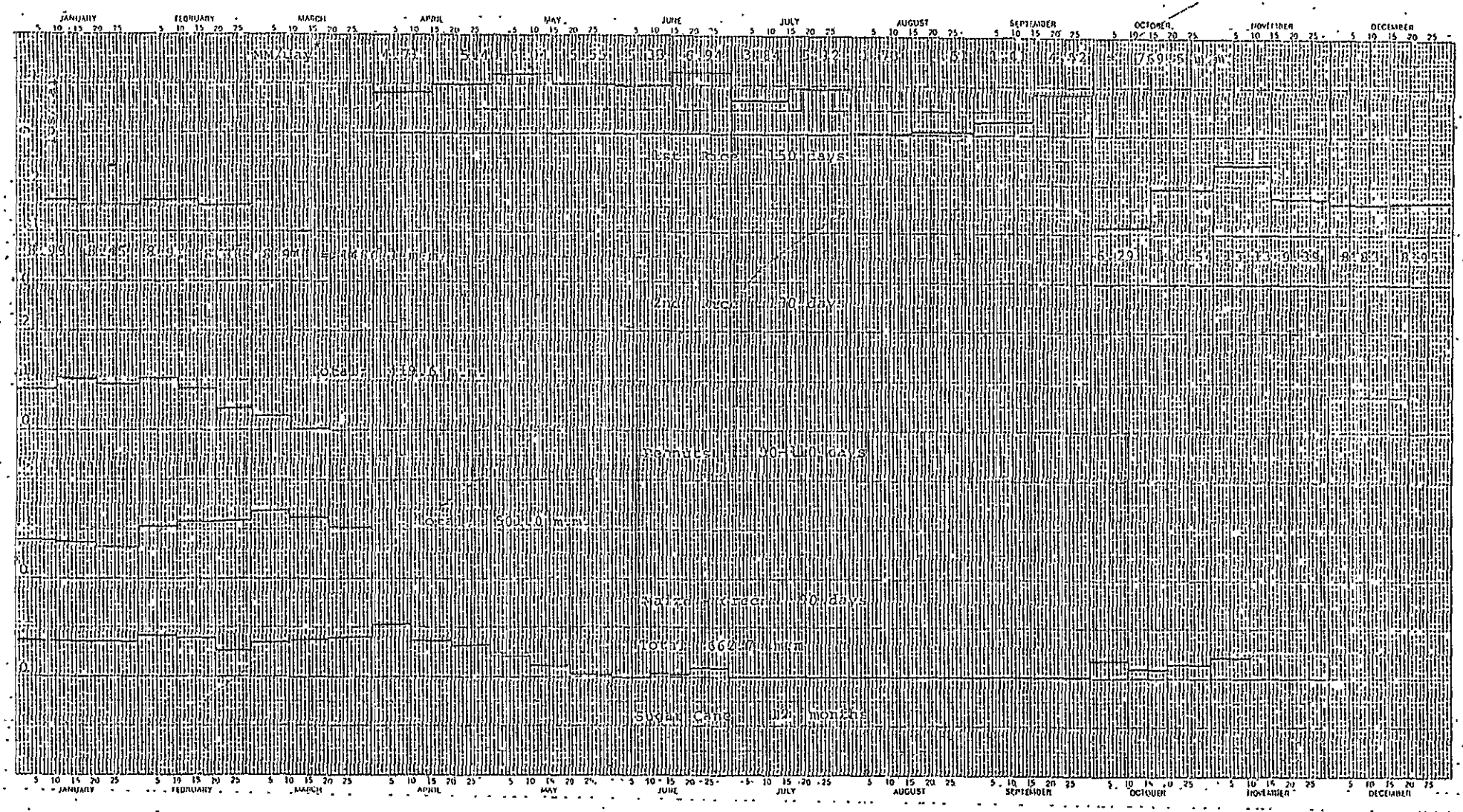
Cropping Sequence



Irrigation Water Requirements for Proposed Cropping Pattern

Figure 12.

1st Approximation
Sakon Nakhon Base



* Irrigation-Water requirement = I.W.R. = C.W.R. - Rf. eff/e

C.W.R. = crop water requirement (Et.kc)
Rf.eff = effective rainfall
e = [illegible]

(a)

Crop Calender and Seasonal Crop Water Requirements.

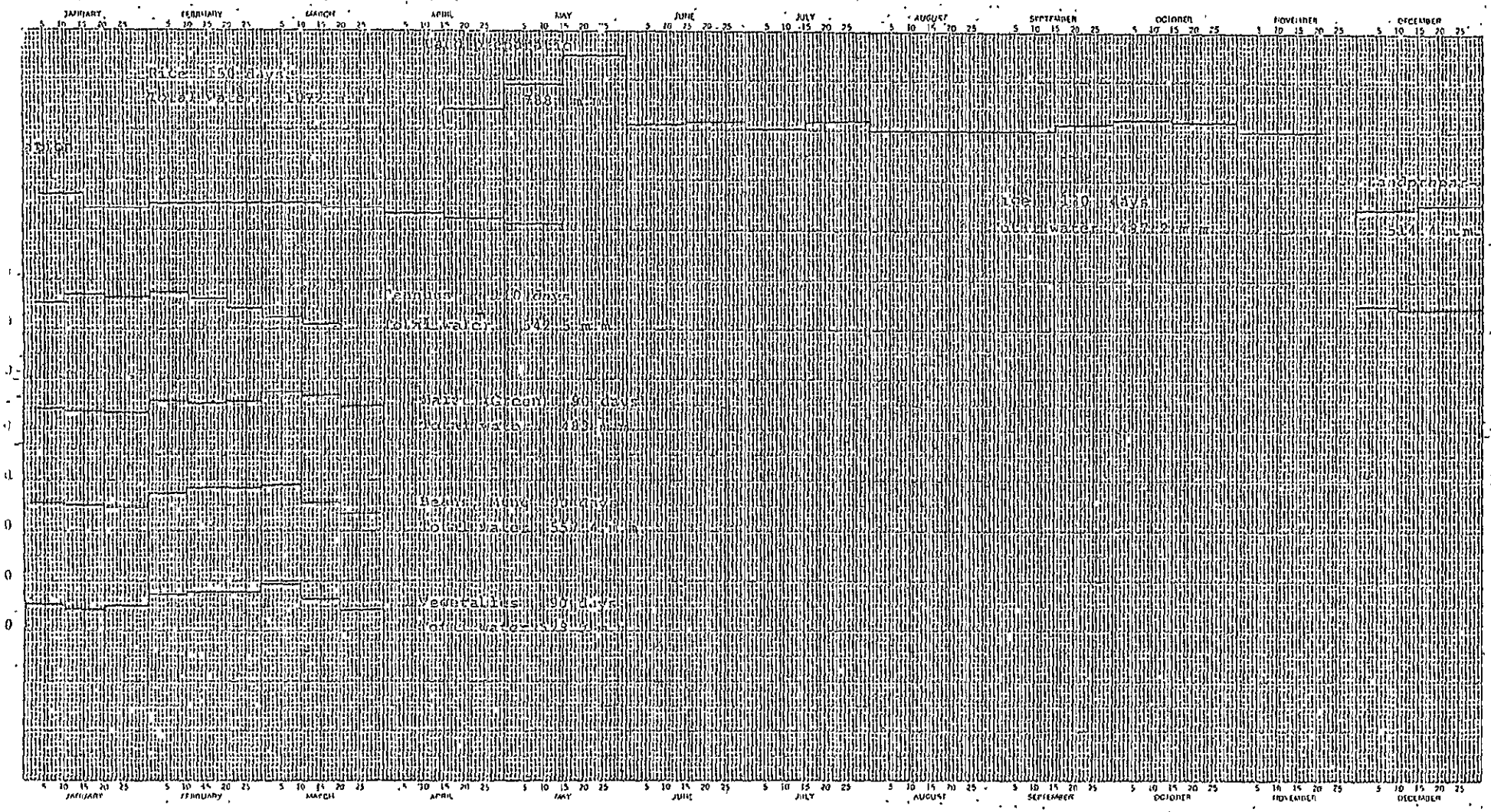


Figure 12

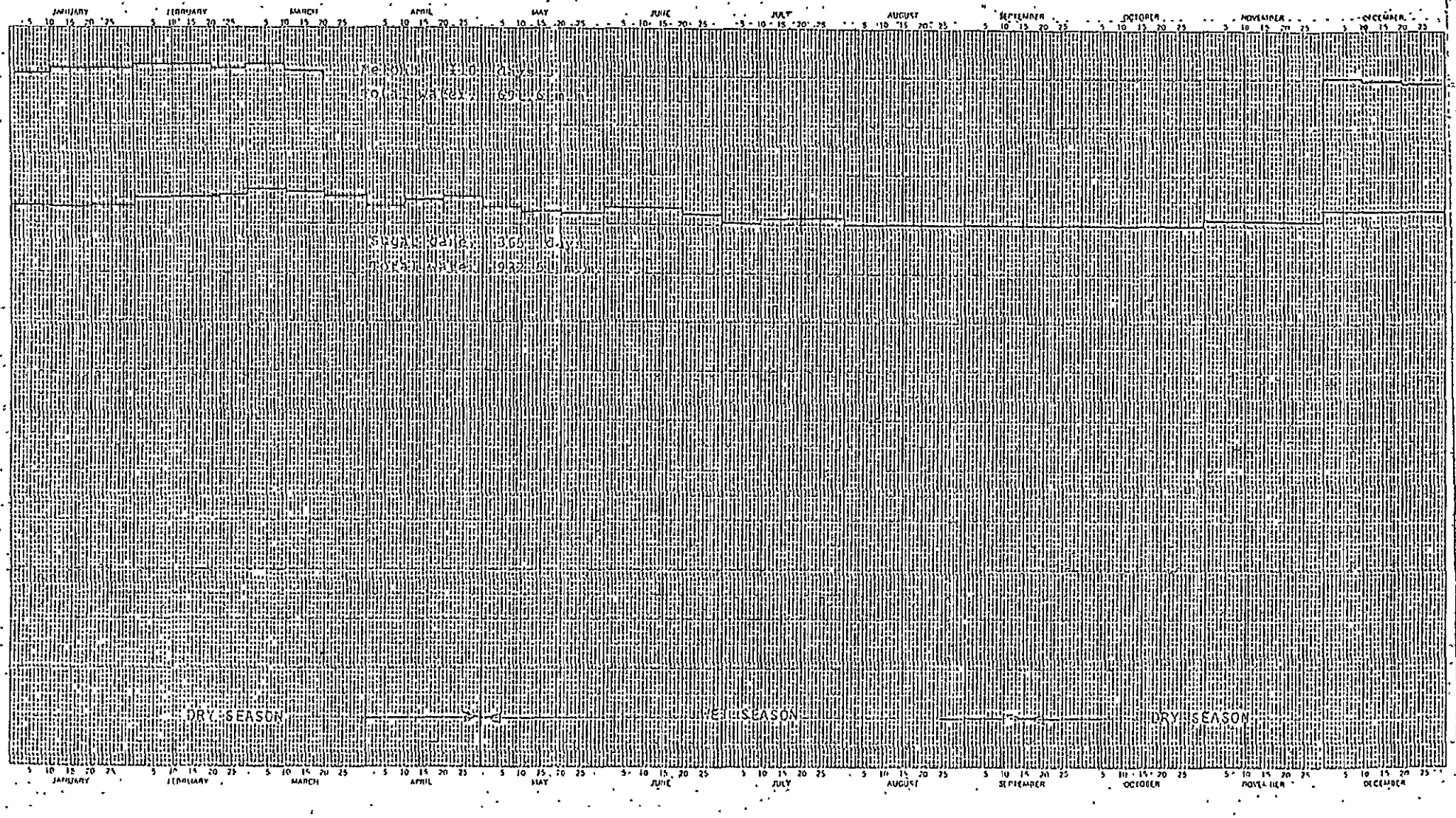

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
10
0
10
0
DRY SEASON
WET SEASON
DRY SEASON

Table No. 9(a)

Irrigation Water Requirement

Calculation Methodology

Crop: Sugar Cane (365 days) Cropping Period: December to December

			Periods													
Period	P	-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M	-		December			January			February			March			April
Days	D	-	10	20	30	40	50	60	70	80	90	100	110	120	130	140
Rooting Depth	d	cm	0	10	20	30	40	50	60	70	80	90	100	100	100	100
Crop Coeff.	Kc	-	.46	.53	.59	.67	.74	.80	.90	.94	.97	1.00	1.04	1.04	1.04	1.04
Stress Factor	Ks	-	1.32	1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep	mm/day	3.25	3.25	3.25	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	4.85	5.35	5.35
Ep(.9-(Kc.Ks)	Es	mm/day	.95	.65	.39	.05	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et	mm/day	1.50	1.72	1.92	2.26	2.50	2.70	3.76	3.93	4.06	4.85	5.04	5.04	5.56	5.56
Kc. Ep - Es	CWR	mm/day	2.45	2.37	2.31	2.26	2.50	2.70	3.76	3.93	4.06	4.85	5.04	5.04	5.56	5.56
Irr. Efficiency	ef	-	-	-	-	-	-	.70	-	-	-	-	-	-	-	-
Effective Rainfall	Rf	mm/day	-	-	-	.97	-	3.57	4.1	4.8	-	11.9	19.9	-	61.5	-
I.W.R.	IWR	mm/day	3.5	3.39	3.30	3.23	3.57	3.86	5.37	5.61	5.80	6.93	6.14	5.87	3.84	4.71
IWR	IWR	l.p.s.* /rai	.065	.063	.061	.060	.066	.071	.099	.104	.107	.128	.114	.109	.071	.087

Table No. 9(b)

Irrigation Water Requirement

Calculation Methodology

Crop: Sugar Cane (365 days) Cropping Period: December to December

		Periods													
Period	P	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M			May			June			July				August	
Days	D	150	160	170	180	190	200	210	220	230	240	250	260	270	
Rooting Depth	d cm	100												100	
Crop Coeff.	Kc	1.00	1.00	1.00	1.00	1.00	1.00	.75	.75	.75	.75	.75	.75	.50	
Stress Factor	Ks	–	–	–	–	–	–	–	–	–	–	–	–	–	
Potential Evap.	Ep mm/day	5.35	4.81	4.81	4.81	4.47	4.47	4.47	4.43	4.43	4.43	3.97	3.97	3.97	
Ep(.9-(Kc.Ks)	Es mm/day	–	–	–	–	–	–	–	–	–	–	–	–	–	
Kc. Ep	Et mm/day	–	–	–	–	–	–	–	–	–	–	–	–	–	
Kc. Ep – Es	CWR mm/day	5.35	4.81	4.81	4.81	4.47	4.47	3.35	3.32	3.32	3.32	2.98	2.98	2.98	
Irr. Efficiency	ef –	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	
Effective Rainfall	Rf mm/day	35.6	46.9	–	69.4	45.6	–	37.2	62.3	–	48.6	74.5	–	83.9	
I.W.R.	IWR mm/day	5.26	3.74	2.99	2.24	3.35	3.63	2.03	0.58	1.04	1.42	–	–	–	
IWR	IWR l.p.s.* /rai	.098	.069	.056	.042	.062	.067	.038	.011	.019	.026	–	–	–	

Table No. 9(d)

Irrigation Water Requirement

Calculation Methodology

Crop: Sugar Cane (365 days) Cropping Period: December to December

		Periods													
Period	P	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M	September				October			November		December				
Days	D	280	290	300	310	320	330	340	350	360	-	-	-	-	-
Rooting Depth	d - CM	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crop Coeff.	Kc	.50	.50	.50	.20	.20	.20	.20	.20	.20	-	-	-	-	-
Stress Factor	Ks	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep mm/day	3.79	3.79	3.79	4.24	4.24	4.24	3.76	3.76	3.76	3.25	3.25	3.25	-	-
Ep(.9-(Kc.Ks)	Es mm/day	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et mm/day	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep - Es	CWR mm/day	1.89	1.89	1.89	0.85	0.85	0.85	0.75	0.75	0.75	-	-	-	-	-
Irr. Efficiency	ef -	69.8		40.4		27.4	15.4	-	5.6	-	-	-	-	-	-
Effective Rainfall	Rf mm/day	-	-	-	-	-	-	.7	-	-	-	-	-	-	-
I.W.R.	IWR mm/day	-	-	-	-	-	.214	1.07	1.07	1.07	-	-	-	-	-
IWR	IWR l.p.s.* /rai	-	-	-	-	-	.004	.020	.020	.020	-	-	-	-	-

Table No. 10

Irrigation Water Requirement

Calculation Methodology

Crop: Groundnuts (Dry Season) Cropping Period: December to April

Period	P	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Periods													
Months	M	December				January			February			March			April
Days	D	10	20	30	40	50	60	70	80	90	100	110	-	-	-
Rooting Depth	d cm	10	15	20	30	40	40	40	40	40	40	40	-	-	-
Crop Coeff.	Kc	.23	.39	.60	.88	1.07	.99	.88	.72	.51	.25	.10	-	-	-
Stress Factor	Ks	1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep mm/day	3.25	3.25	3.25	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	-	-	-
Ep(.9-(Kc.Ks)	Es mm/day	1.94	1.25	.35	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et mm/day	.75	1.27	1.95	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep - Es	CWR mm/day	2.69	2.52	2.30	2.97	3.62	3.35	3.68	3.01	2.13	1.21	.49	-	-	-
Irr. Efficiency	ef -	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	-	-
Effective Rainfall	Rf mm/day	-	-	-	.97	-	3.57	4.1	-	4.8	11.9	-	19.9	-	-
I.W.R.	IWR mm/day	5.27	4.94	4.51	5.24	7.09	6.57	7.22	5.90	4.18	2.37	.96	-	-	-
IWR	IWR l.p.s./rai	.098	.092	.084	.097	.132	.122	.134	.109	.077	.044	.018	-	-	-

Table No: 11

Irrigation Water Requirement

Calculation Methodology

Crop: Maize, Green (1) Cropping Period December to January

Rainfall Return period: 2 years (P = .50)

PARAMETERS			Period													
Period	P	-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M	-	January				February			March						
Days	D	-	10	20	30	40	50	60	70	80	90	10	-	-	-	-
Rooting Depth	d	cm	20	40	55	75	80	80	80	80	80	-	-	-	-	-
Crop Coeff.	Kc	-	.29	.49	.72	.91	.96	1.00	.97	.88	.75	-	-	-	-	-
Stress Factor	Ks	-	1.32	1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep	mm/day	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	4.85	5.35	-	-	-	-
Ep(:9-(Kc:Ks)	Es	mm/day	1.75	.86	-	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et	mm/day	.98	1.66	2.43	3.80	4.01	4.18	4.70	4.28	3.64	-	-	-	-	-
Kc. Ep - Es	CWR	mm/day	2.73	2.52	2.43	3.80	4.01	4.18	4.70	4.28	3.64	-	-	-	-	-
Irr. Efficiency	ef	-	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	-	-	-	-
Effective Rainfall	Rf	mm/day	.97	3.57	-	4.1	-	4.8	-	11.9	19.9	-	-	-	-	-
I.W.R.	IWR	mm/day	4.20	3.88	3.74	5.85	6.17	6.43	7.23	6.58	4.27	-	-	-	-	-
IWR	IWR	l.p.s.* /rai	.078	.072	.069	.108	.114	.119	.133	.122	.079	-	-	-	-	-

Table No. 12

Irrigation Water Requirement

Calculation Methodology

Crop: Maize, Green (2) Cropping Period: January to April
Rainfall Return Period: 2 years (P = .5).

PARAMETERS			Periods													
Period	P	-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M	-		December		-	January			February			-	-	-	-
Days	D	-	10	20	30	40	50	60	70	80	90	100	-	-	-	-
Rooting Depth	d	cm	20	40	55	75	80	80	80	80	80	80	-	-	-	-
Crop Coeff.	Kc	-	.29	.49	.72	.91	.96	1.00	.97	.88	.75	-	-	-	-	-
Stress Factor	Ks	-	1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep	mm/day	3.25	-	3.25	3.38	-	3.38	4.18	-	4.18	4.85	-	-	-	-
Ep(.9-(Kc.Ks)	Es	mm/day	1.68	.82	-	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et	mm/day	.94	1.59	2.34	3.08	3.24	3.38	4.06	3.68	3.14	-	-	-	-	-
Kc. Ep - Es	CWR	mm/day	2.62	2.41	2.34	3.08	3.24	3.38	4.06	3.68	3.14	-	-	-	-	-
Irr. Efficiency	ef	-	-	.65	-	-	.65	-	-	.65	-	-	-	-	-	-
Effective Rainfall	Rf	mm/day	-	-	16.4	.97	-	3.57	4.1	4.8	-	11.9	-	-	-	-
I.W.R	IWR	mm/day	4.03	3.71	2.51	4.74	5.06	5.20	6.25	5.66	4.83	-	-	-	-	-
IWR	IWR	l.p.s.* /rai	.075	.069	.046	.088	.094	.096	.116	.105	.089	-	-	-	-	-

Table No. 13

Irrigation Water Requirement

Calculation Methodology

Crop: Beans, Mung Cropping Period: January to March

	PARAMETERS			Periods													
-	Period	P		1	2	3	4	5	6	7	8	9	10	11	12	13	14
-	Months	M		-	January		-	February			March						
-	Days	D		10	20	30	40	50	60	70	80	90	-	-	-	-	-
-	Rooting Depth.	d	cm	30	20	30	40	60	60	60	60	60	-	-	-	-	-
-	Crop Coeff.	Kc		.27	.46	.71	.90	1.00	.99	.87	.69	.48	-	-	-	-	-
-	Stress Factor	Ks		1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-	-
mm/day	Potential Evap.	Ep	mm/day	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	4.85	-	-	-	-	-
mm/day	Ep(.9-(Kc.Ks)	Es	mm/day	1.84	.99	-	-	-	-	-	-	-	-	-	-	-	-
mm/day	Kc. Ep.	Et	mm/day	.91	1.55	-	-	-	-	-	-	-	-	-	-	-	-
mm/day	Kc. Ep - Es	CWR	mm/day	2.75	2.54	2.39	3.76	4.18	4.14	4.22	3.35	2.37	-	-	-	-	-
-	Irr. Efficiency	ef	-	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	-	-	-	-	-
mm/day 11	Effective Rainfall	RE	mm/day	.97	3.37		4.1	4.8		11.9		19.9	-	-	-	-	-
mm/day 12	I.W.R.	IWR	mm/day	5.39	4.98	4.69	7.37	8.19	8.12	8.27	5.51	3.22	-	-	-	-	-
l.p.s. /13 rai	IWR	IWR	l.p.s. /rai	.099	.092	.087	.137	.152	.150	.153	.102	.060	-	-	-	-	-

Table No. 14

Irrigation Water Requirement

Calculation Methodology

Crop: Vegetables Cropping Period: January to March

				Periods													
-	Period	P		1	2	3	4	5	6	7	8	9	10	11	12	13	14
-	Months	M			January			February			March						
-	Days	D		10	20	30	40	50	60	70	80	90	-	-	-	-	-
-	Rooting Depth	d	cm	10	20	30	40	60	60	60	60	60	-	-	-	-	-
-	Crop Coeff.	Kc		.30	.54	.76	.89	.96	.96	.93	.79	.58	-	-	-	-	-
-	Stress Factor	Ks		1.32	1.32	-	-	-	-	-	-	-	-	-	-	-	-
mm/day	Potential Evap.	Ep	mm/day	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	4.58	-	-	-	-	-
mm/day	Ep(.9-(Kc.Ks)	Es	mm/day	1.70	.63	-	-	-	-	-	-	-	-	-	-	-	-
mm/day	Kc. p.	Et	mm/day	1.01	1.83	-	-	-	-	-	-	-	-	-	-	-	-
mm/day	Kc. Ep - Es	CWR	mm/day	2.71	2.43	2.57	3.72	4.01	4.01	4.66	3.83	2.81	-	-	-	-	-
-	Irr. Efficiency	ef	-	.51	.51	.51	.51	.51	.51	.51	.51	.51	-	-	-	-	-
mm/day 11	Effective Rainfall	RE	mm/day	.97	-	3.57	4.1	-	4.8	-	11.9	19.9					
mm/day 12	I.W.R.	IWR	mm/day	5.31	4.76	5.04	7.29	7.86	7.86	9.14	6 45	4.18	-	-	-	-	-
l.p.s. /13 rai	IWR	IWR	l.p.s. /rai	*0.98	.088	.093	.135	.146	.146	.169	.120	.078	-	-	-	-	-

Table No. 15

Irrigation Water Requirement

Calculation Methodology

Crop: Melons Cropping Period: December to March

PARAMETERS			Periods													
Period	P		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Months	M			December			January			February			March			
Days	D		10	20	30	40	50	60	70	80	90	100	110	-	-	-
Rooting Depth	d	cm	10	20	30	40	60	60	60	60	60	60	60	-	-	-
Crop Coeff.	Kc		.30	.44	.66	.89	1.00	1.01	.94	.89	.84	.80	.75	-	-	-
Stress Factor	Ks		1.32	1.32	1.32	-	-	-	-	-	-	-	-	-	-	-
Potential Evap.	Ep	mm/day	3.25	3.25	3.25	3.38	3.38	3.38	4.18	4.18	4.18	4.85	4.85	-	-	-
Ep(.9-(Kc.Ks)	Es	mm/day	1.64	1.04	.09	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep.	Et	mm/day	.98	1.43	2.15	-	-	-	-	-	-	-	-	-	-	-
Kc. Ep - Es	CWR	mm/day	2.62	2.47	2.24	3.01	3.38	3.41	3.93	3.72	3.51	3.88	3.64	-	-	-
Irr. Efficiency	ef	-	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	-	-	-
Effective Rainfall	Rf	mm/day	-	-	-	.97	-	3.57	4.1	4.8	11.9	19.9		-	-	-
I.W.R.	IWR	mm/day	5.14	4.84	4.39	5.90	6.63	6.69	7.71	7.29	6.88	7.61	6.08	-	-	-
IWR	IWR	l.p.s./rai	.095	0.89	.081	.109	.123	.124	.143	.135	.128	.141	.113	-	-	-

Table No. 16

Irrigation Water Requirement

Calculation Methodology

Crop: Rice, Dry season, 130 days

Cropping Period: December to May

Parameters				Period											
1.	Month			December		January		February		March		April		May	
2.	Days			15	30	45	15	30	45	60	75	90	105	120	135
3.	Potential Evap.	Ep	mm/d	3.25	3.25	3.38	3.38	4.18	4.18	4.85	4.85	5.35	5.35	4.81	4.81
4.	Crop factor	Kc	-	1.0	1.0	1.0	1.06	1.17	1.31	1.40	1.36	1.25	1.12	1.06	.97
5.	Losses	P	-	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
6.	Effective Rainfall	Rf	-	-	-	.97	3.57	6.09	7.2	13.0	21.8	33.8	43.4	51.7	76.3
7.	C.W.R. - Rf	Mi	-	6.25	6.25	6.38	6.58	7.89	8.48	8.92	8.14	7.43	6.09	4.65	2.3
8.		Ii	-	6.76	8.70	10:94	-	-	-	-	-	-	-	-	-
9.		Ai/A	-	.25	.5	.75	1	1	1	1	1	1	1	1	1
10.	Irr. Efficiency	ef	%	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.7
11.	Irr. Water Req.	I.W.R.	mm/d	8.78	11.30	14.21	8.55	10.25	11.01	11.58	9.12	7.40	5.02	2.59	-
12.	Irr. Water Req.	I.W.R.	lps/ra	.163	.209	.263	.158	.189	.204	.215	.169	.137	.093	.048	-

Table No. 17

Irrigation Water Requirement

Calculation Methodology

Crop: Rice, Local Glutinous (150 days)

Cropping Period: April to November

Parameters				Period														
1.	Month			April		May		June		July		August		September		October		November
2.	Days			-	15	30	45	15	30	45	60	75	90	105	120	135	150	-
3.	Potential Evap.	Ep	mm/d	-	5.35	4.81	4.81	4.47	4.47	4.43	4.43	3.97	3.97	3.79	3.79	4.24	4.24	3.76	3.76
4.	Crop factor	Kc	-	-	1.0	1.0	1.0	1.05	1.12	1.27	1.36	1.40	1.38	1.29	1.195	1.09	.95	-	-
5.	Perculation Losses	P	mm/d	-	3.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.	Effective Rainfall	Rf	mm/d	-	43.4	51.7	76.3	60.4	55.6	96.4	75.2	100.4	112.9	91.4	52.9	32.5	18.3	5.6	-
7.	C.W.R. - Rf	Mi	"	-	5.46	4.36	2.72	1.67	2.30	.199	2.01	-	-	-	2.00	3.45	-	-	-
8.		Ii	-	-	6.45	14.13	19.88	-	-	-	-	-	-	-	-	-	-	-	-
9.		Ai/A	-	-	.33	.67	1.0	-	-	-	-	-	-	-	-	-	-	-	-
10.	Efficiency	ef	%	-	0.77	0.77	0.77	0.77	0.77	0.77	0.77	-	-	-	-	-	-	-	-
11.	Irr. Water Req.	I.W.R.	mm/d	-	8.38	18.35	25.81	2.16	2.99	2.26	2.61	-	-	-	2.60	4.49	3.81	-	-
12.	Irr. Water Req.	I.W.R.	lps/ra	-	.155	.339	.478	.040	.055	.005	.05	-	-	-	.048	.083	.071	-	-

Appendix 1

Calculation of Irrigation Water Requirements for Initiating the Rice Crop

1. Basic Equation (1)

$$Ii = \left[\frac{Ai-1}{A} \times Mi \right] + \left[\frac{Ai-Ai-1}{A} \times \frac{Mi}{1-e^{-Mi}} \Delta t/s \right]$$

where

Mi = C.W.R. - Rf for interval Ii, in mm/day

Ai = Proportional area to be initiated in period Δt.

Δt = incremental period of total time T, to complete establishment of rice (soaking, land preparation and transplanting)

S = depth of water required for pre-soaking, land preparation and establishing initial water layer, in mm.

Ai = proportion of total area A, to be prepared in Δt.

A = Total area to be prepared usually taken as unity (A = 1.0).

(All dimension taken in mm per day).

2. Calculaton for Dry Season Rice crop, 130 day period.

1. Pre-saturation water requirement.

$$V = d \times \frac{P}{100} (1 - m./100)$$

where

V = saturation volume, mm
d = depth to be saturated, mm
p = porosity, percent
m = dry soil moisture content, percent.

Porosity = 38.75%
Moisture content of dry soil = 30%
Depth to be saturated = 500 mm

$$V = 500 \times \frac{38.75}{100} (1 - 30/100)$$

$$= 135.6 \text{ mm} \quad \text{Say } \underline{140} \text{ mm}$$

2. Providing for water layer after presaturation say 100 mm.

3. Therefore, S, will be

pre - saturation	140	mm
land preparation	100	mm
losses	10	mm
S =	250	mm

4. Time for land preparation
T = 45 days, for 4 periods, Δt = 45/4 = 11.25 days,

5. The value of Mi for each 15 day interval is

$$Mi = \left[(Ep.\ Kc) + P\right] - Rf/15$$

where,

Ep = Potential evaportranspiration for the period, mm/day
Kc = periodic crop Coefficient
P = losses, percolation and seepage

Rf/15 = effective rainfall for rice (see Table 6) for 15 day periods taken from Table 2.

(These values have been tabulated in Table 16 and 17)

M_1	=	Dec.,	15 days.	M	=	6.25	mm/day
M_2	=	Dec.,	30 days.	M	=	6.25	"
M_3	=	Jan.,	45 days	M	=	6.38	"
M_4	=	Jan.,	60 days	M	=	6.58	"

6. Trial Calculations using 4 intervals for Ai (For i = 1,2,3,4)

i = 1, A_1 = .25 And, A = 1,
i = 2, A_2 = .50 Ai-1 = 0
i = 3, A_2 = .75
i = 4, A_4 = 1.00

$\Delta t/s$ = 11.25/250 = 0.045

i	Mi	x = -Mi.Δt/S	e^{-x}	$1-e^{-x}$
1	6.25	-.2813	.7549	.2452
2	6.25	-.2813	.7549	.2452
3	6.38	-.2871	.7504	.2496
4	6.58	-.2961	.7437	.2563

Using basic equation (1)

$$I_1, \quad \frac{A_{i-1}}{A} = 0, \quad \frac{A_i - 0}{A} = \frac{.25-0}{1} = .25$$

$$\therefore \quad I_1 = \left[0\right] + \left[\frac{.25}{1} \times 6.25/.2452\right] = 6.37$$

$$I_2 = \left[\frac{.25}{1} \times 6.25\right] + \left[\frac{(.5 - .25)}{1} \times 6.25/.2452\right] = 7.93$$

$$I_3 = \left[\frac{.50}{1} \times 6.38\right] + \left[(.75 - .5) \times 6.38/.2496\right] = 9.58$$

$$I_4 = \left[\frac{.75}{1} \times 6.58\right] + \left[\frac{(1.0 - .75)}{1} \times 6.58/.2563\right] = 11.35$$

Therefore for,

A_1	=	0.25	I_1	= 6.37	mm/day
A_2	=	0.50	I_2	= 7.93	mm/day
A_3	=	0.75	I_2	= 9.58	mm/day
A_4	=	1.00	I_4	= 11.35	mm/day

Note that the field preparation period I is devided into n equal parts, $T = n\,\Delta t$.

However, these I values have been adjusted for the three 15 days periods to fit the calculation procedure in Tables 16 and 17, for 130 day rice.

I_{15} = 6.76 mm/day

I_{30} = 8.70 mm/day

I_{45} = 10.94 mm/day

This trial calculation for 130 day dry season is acceptable.

7. Trial Calculation for 150 day wet season rice.

Use previous methodology for (6).

A_i , $i = 1, 2, 3.$

Δt = 15 days for T = 45 days

n = 3 = i

i = 1 , A_1 = 0.33

i = 2 , A_2 = 0.66

i = 3 , A_3 = 1.00

and $A_i - 1 = 0$, A = 1.00

$\Delta t/S$ = 15/250 = mm/day

Data from Table .....

M_1	=	April,	15 days	M	=	5.46
M_2	=	May ,	30 days	M	=	4.36
M_3	=	May ,	45 days	M	=	2.72

i	Mi	x =	$- Mi\ \Delta t/S$	e^{-x}	$1-e^{-x}$
1	5.46		- .3276	.7201	.2793
2	4.36		- .2616	.7698	.2302
3	2.72		- .1632	.8494	.1506

Using the previous equation.

$$I_1 = [\ 0\ ] + [.33 \times 5.46/.2793] = 6.45$$
$$I_2 = [.33 \times 4.36] + [.67 \times 4.36/.2302] = 14.13$$
$$I_3 = [.67 \times 2.72] + [1.00 \times 2.72/.1506] = 19.88$$

Therefore, for,

A_1 =	0.33	I_1 =	6.45	mm/day
A_2 =	0.67	I_2 =	14.13	"
A_3 =	1.00	I_3 =	19.88	"

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