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Evaluation of Environmental Parameters in the Humid Tropics for Crop Scheduling Purposes

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EVALUATION OF ENVIRONMENTAL PARAMETERS IN THE HUMID TROPICS FOR CROP SCHEDULING PURPOSES

by

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ABOUT THIS REPORT

Data in this report are presented in metric units. Monetary values have been converted to U.S. dollars at the current (May, 1978) exchange rate.

A double asterisk (**) means significant at the 1% level; a single asterisk (*) means significant at the 5% level; a cross (†) means significant at the 10% level.

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INTRODUCTION

Fluctuations in weather patterns have been the bane of farmers for centuries. Drought, floods, hurricanes (typhoons), tornadoes, thunderstorms, cold fronts, etc., occur with a wide range of intensity and frequency. Although meteorologists are learning more about these atmospheric phenomena the art of forecasting, particularly of severe storms, is still primitive. However, a station's climatic data does provide a guide to the most probable pattern of variance of the basic weather parameters.

Farmers have learned to plan around weather hazards through years of experience but their intuition is difficult to quantify. Agricultural planners need to know the probabilities of a given phenomena for entire cropping periods in order to optimize crop scheduling. In the tropics, where fields are often cultivated the year around, it may be necessary to plan as much as three years ahead (4). Sophisticated weather data is gathered at few stations in the tropics. A system for analyzing environmental variations for crop planning must be based on data normally recorded at small weather stations. The method of analysis presented here meets this criterion. The method was first developed as a guide for research and production interns of the Asian Vegetable Research and Development Center to enable them to analyze the environmental conditions of their home station for crop planning purposes.

The methodology presented can be used to include additional variables, such as population or intensity of insect pests or pathogens; market price fluctuations, or labor availability. The parameters selected for inclusion are those which are of prime importance in the humid lowland tropics. In this environment, crop production is more severely affected by too much, rather than too little, rainfall.

The cropping pattern analysis has been limited to consideration of six vegetable and legume crops being given primary research attention at AVRDC, namely: tomato, *Lycopersicon esculentum*; white potato, *Solanum tuberosum*; Chinese cabbage, *Brassica pekinensis*; soybean, *Glycine max*; sweet potato, *Ipomoea batatas*, and mungbean, *Vigna radiata* and rice, *Oryza sativa*. Rice has been included because it is the foremost crop in Asia. It is said that "almost everying begins with rice", (1), hence, with few exceptions, lowland vegetable crops must be fitted into a rice-based cropping system. It has been assumed that water enough for survival is available at all times and is not a production constraint.

METHOD

Data required:

<u>Primary climatic data</u>

1. Station latitude
2. Monthly precipitation (mm)
3. Mean monthly temperature (^{o}C)

4a. Sunshine (%)[a]
4b. Monthly tabulation of average daily solar radiation in a cloudless sky by latitude (cal/cm^2)
5. Severe storm frequency

Other data

Environmental limits to normal growth for each crop

TABULATION OF CROPPING PERIODS AND GROWTH CONSTRAINTS

One of the most crucial steps in this evaluation procedure is the determination of the acceptable range of environmental conditions for each crop. For convenience, crops are listed under headings indicating periods of growth ranging from 2 to 5 months (Table 1). Varietal differences in maturity may dictate that a given crop be listed under more than one heading (i.e. soybean can be either a 3 or 4 month crop, depending on the variety and season planted). In addition there may be genotypes within a given cropping period whose responses to environment differ. AVRDC is seeking heat tolerant biotypes of Chinese cabbage, white potato and tomato. Therefore, two columns of acceptable ranges for environmental parameters have been made for each of these crops, one for heat tolerant cultivars (HT) and one for heat sensitive cultivars (HS) (5).

A considerable amount of subjective judgment is required in quantifyin the environmental limits for normal growth of each crop. One may find that the initial limits are too restrictive or too lax after completing the first evaluation. It is relatively easy to make other trials once the environmental data tables have been prepared. A satisfactory determination of optimal cropping periods may require several trials. In carrying out these calculations one begins to get a feel for the importance of the change of a given variable. This form of "sensitivity analysis" leads to a keener appreciation of the environmental constraints to growth. The principal environmental parameters affecting growth are given below, and in Table 1, in the approximate order of importance for southern Taiwan. The number and order will vary from location to location. Therefore, the list should be reordered for each locale.

Solar Radiation is assumed to be beneficial to most crops at the highest level possible for the entire length of the cropping period. Solar radiation during the last month is correlated with yield for some crops.

For others a low level is desirable. The preferred level of solar radiation, if any, is specified in relative terms, high, H; moderate, M; or low, L.

Maximum and Minimum Temperature limits for normal growth of each crop is specified in Table 1. It is assumed that the acceptable maximum temperature for tomato and potato is raised for heat tolerant germplasm without affecting the minimum temperature limit. This seems to be substantiated by the high yields recorded in cool season yield trials for

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[a]Not required if sufficiently long records (5-10 years) of solar radiation data are available.

Table 1. Desired growth environment for 6 AVRDC vegetable crops[a] and rice.

Parameters	Two month crops		Three month crops						Four month crops			Five month crops		
	Chinese cabbage		Chinese cabbage		White potato		Mungbean	Soybean	Soybean	Sweet potato	Rice	Sweet potato	Tomato	
Radiation (cal/cm²)[b]	HS[c]	HT[d]	HS	HT	HS	HT							HS	HT
Whole crop	H	H	H	H	-	-	H	-	-	-	-	H	H	H
Last month	-	-	-	-	H	H	-	H	H	H	H	-	-	-
Temperature(°C)														
Maximum	25	30	25	30	20	30	35	30	30	35	35	35	25	35
Minimum	10	20[e]	10	20[e]	15	15	20	15	15	10	15	10	15	15
Acceptable typhoon probability (%)														
Whole crop	5	5	5	5	10	10	5	5	5	25	65	25	5	5
Last two months	5	5	5	5	5	5	0	0	0	20	15	20	0	0
Last month	0	0	0	0	5	5	0	0	0	20	5	20	0	0
Tolerable precipitation (mm)[a]														
Whole crop	M	M	M	M	M	M	M	M	M	H	H	H	M	M
Harvest period	-	-	-	-	M	M	L	L	L	M	M	M	M	H
Allowable thunderstorm probability at harvest (%)	5	5	5	5	5	5	0	0	0	15	15	15	0	0
Harvest month(s)	2	2	3	3	3	3	2,3	3	4	4	4	5	4,5	4,5

[a]CC, Chinese cabbage; WP, white potato; MB, mungbean; SB, soybean; SP, sweet potato; T, tomato. [b]H = High M = Moderate L = Low
[c]HS = Heat sensitive [d]HT = Heat tolerant [e]Tends to bolt at lower temperatures. Sources: (2) (3) (6).

heat tolerant germplasm of these crops. Heat tolerant Chinese cabbage, on the other hand, tends to bolt at acceptable minimum temperatures for heat sensitive genotypes. Therefore, a higher minimum temperature has been specified for heat tolerant Chinese cabbage.

Typhoon Probability is relatively high for Taiwan. The highest acceptable limits of probability, expressed as a percent chance of occurrence during the whole crop, the last two months and the last month has been estimated. Of course zero typhoon probability would be preferable for all crops. The percentages assigned are somewhat arbitrary. Their absolute value is not important, but their relative value gives an indication of when typhoon damage would cause the most severe crop or yield loss.

Precipitation tolerance during the whole crop or in the harvest period has been indicated in relative terms, L, M, or H, based on the effect on yield. The hazard value of having too much rain has been emphasized. High rainfall during harvest is most harmful to the legume crops.

Thunderstorm Probability at Harvest is included in Table 1 as an example of incorporation of other severe weather frequency data which may be available at a given station. Thunderstorms at harvest are a hazard to field staff and may reduce yield.

The Harvest Month is indicated for reference purposes. Some crops are harvested only once, but others may have several harvests extending over a two month period.

PREPARATION OF ENVIRONMENTAL DATA TABLES

The data from Kaohsiung, Taiwan, is used as an example to illustrate the procedure. Basic to all calculations is the premise that to be of use to a farmer or crop planner the environmental variable for the whole crop must be known prior to planting. To assist in evaluating planting decisions the data for all the selected parameters are tabulated opposite the planting month.

Solar Radiation

Kaohsiung is located at 22°37'N latitude or approximately, (to the nearest one-half degree) 22.5°N. Interpolating 22.5°N data as midway between 20 and 25°N, the average daily solar radiation in a cloudless sky is obtained from Table 2a (North latitudes) (8) and entered in column 2 of Table 3. The mean percent sunshine observed each month (2) is entered in column 1 of Table 3. The average monthly solar radiation is calculated as a product of column 1 and column 2 and entered in column 3.[b] The numbers in column 3 also correspond to the mean daily solar radiation for a crop with length of one month.

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[b]This mean of caculating solar radiation may over estimate absolute values, but the relative monthy values should approximate actual observations with sufficient accuracy for the purpose for which they are used in this study.

Table 2a. Average daily solar radiation in a cloudless sky (North latitudes). (cal/cm^2)

Ø°	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL	AVE.
90	0	0	3	333	706	867	768	416	80	0	0	0	3,173	264
85	0	0	23	340	703	860	755	423	100	0	0	0	3,204	267
80	0	0	77	360	690	840	742	432	143	16	0	0	3,300	275
75	0	18	129	390	577	817	716	445	193	42	0	0	3,427	286
70	0	57	194	437	661	787	684	471	250	87	17	0	3,645	304
65	23	100	258	483	648	760	677	503	317	139	47	6	3,961	330
60	58	154	319	533	671	763	690	539	377	197	87	36	4,424	369
55	100	221	377	577	690	780	706	577	430	252	133	74	4,917	410
50	155	293	429	617	716	790	729	616	480	313	193	126	5,457	455
45	216	368	477	650	729	797	748	648	527	371	260	190	5,981	498
40	284	436	529	677	742	800	755	674	567	426	323	248	6,461	538
35	345	500	568	700	742	800	761	697	603	474	380	313	6,883	574
30	403	554	600	713	742	793	755	703	637	519	437	371	7,227	602
25	455	600	629	720	742	780	745	703	660	561	487	423	7,505	625
23.5	472	612	636	720	737	774	741	701	666	572	502	438	7,571	631
22.5	478	620	640	720	734	770	737	700	670	579	512	448	7,608	644
20	500	639	652	720	726	760	729	697	680	597	537	474	7,711	643
15	545	679	671	713	706	733	706	684	697	623	530	519	7,856	655
10	584	707	681	707	684	700	681	664	707	648	617	564	7,944	662
5	623	729	690	700	652	663	645	645	710	664	650	606	7,977	645
0	652	746	694	680	623	627	616	623	707	684	680	619	7,951	663

Adapted from similar Table in (8).

Table 2b. Average daily solar radiation in a cloudless sky (South latitudes)

Ø°	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL	AVE.
0	652	746	694	680	623	627	616	623	707	684	680	619	7,951	663
5	648	764	690	663	590	587	577	590	693	690	727	677	7,896	658
10	710	779	681	640	571	543	526	558	680	690	727	710	7,815	651
15	729	786	664	610	516	497	497	519	657	687	747	739	7,648	637
20	748	786	645	573	474	447	445	481	630	677	753	761	7,420	618
25	761	786	626	533	419	400	406	439	600	664	767	777	7,178	598
30	771	779	600	497	384	353	358	390	567	648	767	794	6,908	576
35	774	761	568	453	336	300	310	342	530	629	767	806	6,576	548
40	774	736	529	407	281	243	261	290	477	603	760	813	6,174	514
45	774	711	490	357	229	183	203	236	447	571	747	813	5,761	480
50	761	675	445	307	174	127	148	177	400	536	727	806	5,283	440
55	748	636	397	250	123	77	97	123	343	497	707	794	4,792	399
60	729	593	348	187	77	33	52	74	283	455	700	787	4,318	360
65	723	546	294	130	36	3	13	32	223	406	693	790	3,889	324
70	729	507	236	73	3	0	0	0	167	368	700	803	3,586	299
75	748	479	184	30	0	0	0	0	117	336	707	819	3,420	285
80	774	457	139	0	0	0	0	0	70	313	730	938	3,322	277
85	794	443	94	0	0	0	0	0	30	297	747	858	3,263	272
90	803	439	55	0	0	0	0	0	0	290	753	871	3,211	268

Adapted from similar Table in (8).

Table 3. Accumulative solar radiation for crops 1 to 5 months length in Kaohsiung, Taiwan, ROC (cal/cm^2).

Planting month	Sunshine	Clear sky radiation 22.5°N	Crop length (mo.) One	Two	Three	Four	Five
	(%)	(cal/cm^2)					
JAN	54	478	258	605	944	1,333	1,747
FEB	56	620	347	686	1,075	1,486	1,848
MAR	53	640	339	827	1,139	1,501	1,877
APR	54	720	389	800	1,162	1,538	1,874
MAY	56	734	411	773	1,149	1,485	1,874
JUN	47	770	362	738	1,074	1,463	1,828
JUL	51	737	376	712	1,101	1,465	1,763
AUG	48	700	336	725	1,090	1,387	1,629
SEP	58	670	289	754	1,051	1,293	1,551
OCT	63	579	365	662	904	1,162	1,509
NOV	58	512	297	539	797	1,144	1,483
DEC	54	448	242	500	847	1,186	1,575

Source: (2) Table 2a.

A two month crop planted in January would have a total solar radiation equal to the sum of the radiation for January and February (i.e. 258 + 347 = 605)[c] values for a two month cropping period are entered in column 4, Table 3. The values for a 3 month crop are in 5; 4 month crop in column 6, etc. Therefore, the accumulated solar radiation for a 5 month crop beginning in January is 1747 cal/cm^2, and 1828 cal/cm^2 for a 5 month crop planted in June.

The mean daily solar radiation in the last month is tabulated in Table 4. The mean daily solar radiation of a 3 month crop planted in January is equal to the mean value for March. However, this value is entered opposite January in the 3 month crop length column. Similarly, in the 4 month column, opposite June, 389 is entered (September is the 4th month of a crop planted in June, therefore, the mean daily solar radiation for September, 389, is entered opposite the planting month, June).

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[c]Since these numbers represent monthly averages of daily values each should be multiplied by the number of days per month and their sum divided by the mean days per month.

$$\frac{(258 \times 31) + (347 \times 28)}{29.5} = 600$$

Since adding the mean monthly values results in less than a 1% error, the simpler calculations appear acceptable for the purposes of this paper.

Table 4. Mean daily solar radiation in the last month of crops ranging from 1-5 mo. in length, planted in month indicated, Kaohsiung, Taiwan, ROC.

Planting month	Crop length (mo)				
	one	two	three	Four	Five
	----------(cal/cm^2)----------				
JAN	258	347	339	389	411
FEB	347	339	389	411	362
MAR	339	389	411	362	376
APR	389	411	362	376	336
MAY	411	362	376	336	389
JUN	362	376	336	389	365
JUL	376	336	389	365	297
AUG	336	389	365	297	242
SEP	389	365	297	242	258
OCT	365	297	242	258	347
NOV	297	242	258	347	339
DEC	242	258	347	339	389

Source: (2)

Temperature

It has been assumed that the temperature range over the entire cropping period of the planting is more useful than the average temperature. Hence, the range of mean monthly temperatures for each cropping period is given in Table 5.

Typhoon Probability

A detailed analysis of the paths of typhoons affecting Taiwan was made for a 20 year period (3). During this period 9 typhoons followed a track passing over the Kaohsiung area. Using the frequency distribution of the number of typhoons occuring in each month. The monthly typhoon probability for a given year was calculated.[d]

Using a technique similar to that described for analyzing solar radiation, the probability, expressed as a percent, of typhoon occurrence during one to five month crop periods was tabulated (Table 6a).

[d]This estimate ignores typhoon passing nearby but not directly over Kaohsiung, which may also cause severe crop damage. These can be included without difficulty if so desired.

Table 5. Expected maximum and minimum mean monthly temperatures during crops ranging in length from two to five months, Kaohsiung, Taiwan, ROC.

Crop length	JAN		FEB		MAR		APR		MAY		JUN	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	(°C)											
Two months	19.2	18.6	21.7	19.2	24.5	21.7	27.2	24.5	27.8	27.2	28.2	27.8
Three months	21.7	18.6	24.5	19.2	27.2	21.7	27.8	24.5	28.2	27.2	28.2	27.8
Four months	24.5	18.6	27.2	19.2	27.8	21.7	28.2	24.5	28.2	27.2	28.2	27.5
Five months	27.2	18.6	27.8	19.2	28.2	21.7	28.2	24.5	28.2	27.2	28.2	25.7

Crop length	JUL		AUG		SEP		OCT		NOV		DEC	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	(°C)											
Two months	28.2	27.9	27.9	27.5	27.5	25.7	25.7	23.2	23.2	20.1	20.1	18.6
Three months	28.2	27.5	27.9	25.7	27.5	23.2	25.7	20.1	23.2	18.6	20.1	18.6
Four months	28.2	25.7	27.9	23.2	27.5	20.1	25.7	18.6	23.2	18.6	21.7	18.6
Five months	28.2	23.2	27.9	20.1	27.5	18.6	25.7	18.6	23.2	18.6	21.7	18.6

Source (2).

Table 6a. Typhoon probability in Kaohsiung, Taiwan, ROC (%)

Planting month	Typhoon probability Length of crop (mo.)				
	One[a]	Two	Three	Four	Five
	(%)				
JAN	0	0	0	0	0
FEB	0	0	0	5	10
MAR	0	0	5	10	25
APR	0	5	10	25	45
MAY	5	10	25	45	45
JUN	5	20	40	40	40
JUL	15	35	35	35	35
AUG	20	20	20	20	20
SEP	0	0	0	0	0
OCT	0	0	0	0	0
NOV	0	0	0	0	0
DEC	0	0	0	0	0

Source (3).

The probability of typhoons in the last or last two months of a crop are given in Table 6b and 6c respectively.

Precipitation

The estimated accumulated precipitation for crops ranging from one to five months is given in Table 7a. The accumulative precipitation in the last month or last two months of the same cropping periods is given in Table 7b.

Thunderstorms

The estimated probability (expressed as a percent) of thunderstorms occuring on a given day during the harvest or planting month is entered in Table 8.

SUMMATION OF CROP ENVIRONMENT BY CROP LENGTHS

Drawing on the data in Tables 2-8, the variation in environmental parameters for a given cropping period were summarized. Since AVRDC crops and rice have a maturity range from 2-5 months, no summary was prepared for one month or beyond five months. Given different crops, summations for other crop lengths could be prepared with little difficulty,

Table 6b. Typhoon probability in a last month of crops ranging in length from one to five months, Kaohsiung, Taiwan, ROC.

Planting month	Crop length (mo.)				
	One	Two	Three	Four	Five
	(%)				
JAN	0	0	0	0	5
FEB	0	0	0	5	5
MAR	0	0	5	5	5
APR	0	5	5	15	20
MAY	5	5	15	20	0
JUN	5	15	20	0	0
JUL	15	20	0	0	0
AUG	20	0	0	0	0
SEP	0	0	0	0	0
OCT	0	0	0	0	0
NOV	0	0	0	0	0
DEC	0	0	0	0	0

Source: (3).

Table 6c. Typhoon probability in last two months of 1-5 month cropping period, Kaohsiung, Taiwan, ROC.

Planting months	Crop length (mo.)				
	One	Two	Three	Four	Five
	(%)				
JAN	-	0	0	0	5
FEB	-	0	0	5	10
MAR	-	0	5	10	20
APR	-	5	10	20	35
MAY	-	10	20	35	20
JUN	-	20	35	20	0
JUL	-	35	20	0	0
AUG	-	20	0	0	0
SEP[a]	-	0	0	0	0

[a]Remaining months probability equals zero.
Source: (3).

Table 7a. Accumulated precipitation for cropping periods ranging from 1-5 months in Kaohsiung, Taiwan, ROC.

Planting month	Crop length (mo.)				
	One	Two	Three	Four	Five
	mm				
JAN	10.8	27.2	67.1	122.6	277.7
FEB	16.4	56.3	111.8	266.9	693.3
MAR	39.9	95.4	250.5	676.9	1110.4
APR	55.5	210.6	637.0	1070.5	1440.6
MAY	155.1	581.5	1015.0	1385.1	1543.5
JUN	426.4	819.9	1230.0	1388.4	1429.3
JUL	433.5	803.6	962.0	1002.9	1024.9
AUG	370.1	528.5	569.4	591.4	604.4
SEP	158.4	199.3	221.3	234.3	245.1
OCT	40.9	62.9	75.9	86.7	103.1
NOV	22.0	35.0	45.8	62.2	102.1
DEC	13.0	23.8	40.2	80.1	135.6

Source: (2).

using the same procedures employed in this paper. Environmental data for 2, 3, 4, and 5 months crops are contained in Tables 9, 10, 11, and 12 respectively. Data for a given cropping period are listed under the planting month for the crop. For example, 1501 cal/cm^2 of solar radiation, on the average, would fall during a 4 month crop planted in March. Therefore, this figure is listed in the March column of Table 11 (Four month crop data). For the same crop, planted in March, the expected insolation during the last month of a 4 month crop, is 362 cal/cm^2. Although this is the expected radiation for June, it is entered under the crop planting month, March. The advantage of this procedure is that the range of all the selected variables for a given crop can be scanned easily in one column. They are listed under the planting month, since that is the time the decision on whether to plant seed and commit inputs must be made. The change in crop environment to be expected throughout the cropping period if planting is advanced or delayed one month can easily be seen by comparing the data in adjacent columns.

Tables 9, 10, 11, and 12 are used in conjunction with the crop environmental constraints in Table 1, to prepare optimal crop planting dates tabulated in Tables 13, 14, 15, 16, 17, and 18.

EVALUATION OF BOUNDARY CONDITIONS FOR BEST PLANTING OPTIONS

The planting periods in which the expected values of the environmental

Table 7b. Accumulated precipitation during harvest periods of crops ranging from one to five months in length, Kaohsiung, Taiwan, ROC.

Planting month	Precipitation in last month crop length(mo.) One	Two	Three	Four	Five	Last 2 months of a 3 month crop[a]	Last 2 months of a 5 month crop[b]
	(mm)						
JAN	10.8	16.4	39.9	55.5	155.1	56.3	210.6
FEB	16.4	39.9	55.5	155.1	426.4	95.4	581.5
MAR	39.9	55.5	155.1	426.4	433.5	210.6	859.9
APR	55.5	155.1	426.4	433.5	370.1	581.5	803.6
MAY	155.1	426.4	433.5	370.1	158.4	859.9	528.5
JUN	426.4	433.5	270.1	158.4	40.9	803.6	199.3
JUL	433.5	370.1	158.4	40.9	22.0	528.5	62.9
AUG	370.1	158.4	40.9	22.0	13.0	199.3	35.0
SEP	158.4	40.9	22.0	13.0	10.8	62.9	23.8
OCT	40.9	22.0	13.0	10.8	16.4	35.0	27.2
NOV	22.0	13.0	10.8	16.4	39.9	23.8	56.3
DEC	13.0	10.8	16.4	39.9	55.5	27.2	95.4

Source: (2).

Table 8. Percent probability of a thunderstorm occuring on a given day during planting or harvest month for Kaohsiung, Taiwan, ROC.

Planting month	Harvest month of crop of length (mo.)				
	One[a]	Two	Three[b]	Four[c]	Five
	(%)				
JAN	0.3	0.6	2.3	4.7	10.3
FEB	0.6	2.3	4.7	10.3	16.3
MAR	2.3	4.7	10.3	16.3	22.6
APR	4.7	10.3	16.3	22.6	24.5
MAY	10.3	16.3	22.6	24.5	15.0
JUN	16.3	22.6	24.5	15.0	3.5
JUL	22.6	24.5	15.0	3.5	0.3
AUG	24.5	15.0	3.5	0.3	0
SEP	15.0	3.5	0.3	0	0.3
OCT	3.5	0.3	0	0.3	0.6
NOV	0.3	0	0.3	0.6	2.3
DEC	0	0.3	0.6	2.3	3.7

Source: (2)
[a]These values also apply for all planting months.
[b]These values also apply for the 3rd month of a 4 month crop. [c]These values also apply for the 4th month of a 5 month crop.

parameters (Tables 9-12) fall within the desired growth range (Table 1) are indicated in Tables 13-18. For example, early maturity Chinese cabbage is a two month crop. For heat sensitive cultivars the temperature during the entire crop should not exceed a range of 10-25°C (Table 1). Referring to the temperature data in Table 9 it is seen that the minimum mean daily temperature in Kaohsiung is never below 10°C, but the maximum mean daily temperature exceeds 25°C during April - October. Therefore, from temperature considerations only, heat sensitive Chinese cabbage can be planted only in November - March. The planting months that correspond to cropping periods in which the temperature falls within the given boundary constraints for heat sensitive Chinese cabbage are noted in Table 13 with a lower case "c". Similarly, the acceptable planting months for heat tolerant Chinese cabbage are noted with a capital "C".

It is important to note that the periods delineated in Tables 13-18 are "acceptable times for planting" not cropping periods.

Table 9. Summary of environmental data for two month crop, planted in indicated month. Kaohsiung, Taiwan, ROC.

Radiation (cal/cm²)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Whole crop	605	686	728	800	773	738	712	725	754	662	539	500
Last month	347	339	389	411	362	376	336	389	365	297	242	347
Temperature (°C)												
Maximum	19.2	21.7	24.5	27.2	27.8	28.2	28.2	27.9	27.5	25.7	23.2	20.1
Minimum	18.6	19.2	21.7	24.5	27.2	27.8	27.9	27.5	25.7	23.2	20.1	18.6
Typhoon probability (%)												
Whole crop	0	0	0	5	10	20	35	20	0	0	0	0
Last two months	0	0	0	5	10	20	35	20	0	0	0	0
Last month	0	0	0	5	5	15	20	0	0	0	0	0
Precipitation (mm)												
Whole crop	27.2	56.3	95.4	210.6	581.5	819.9	803.6	528.5	199.3	62.9	35.0	23.8
Harvest periods												
Last month	16.4	39.9	55.5	155.1	426.4	433.5	270.1	158.4	40.9	22.0	13.0	10.8
Last two months	-	-										
Thunderstorm probability at harvest (%)	0.6	2.3	4.7	10.3	16.3	22.6	24.5	15.0	3.5	0.3	0	0.3

Source: Tables 1-8.

Table 10. Summary of environmental data for three month crop, planted in month indicated, Kaohsiung, Taiwan, ROC.

Radiation (cal/cm^2)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Whole crop	944	1,075	1,139	1,162	1,149	1,074	1,101	1,090	1,051	904	797	847
Last month	339	389	411	362	376	336	389	365	297	242	258	347
Temperature (^{o}C)												
Maximum	21.7	24.5	27.2	27.8	28.2	28.2	28.2	27.9	27.5	25.7	23.2	20.1
Minimum	18.6	19.2	21.7	24.5	27.2	27.8	27.[illegible]	25.7	23.2	20.1	18.6	18.6
Typhoon probability (%)												
Whole crop	0	0	5	10	25	40	35	20	0	0	0	0
Last two months	0	0	5	10	20	35	20	0	0	0	0	0
Last month	0	0	5	5	15	20	0	0	0	0	0	0
Precipitation (mm)												
Whole Crop	67.1	111.8	250.5	637.0	1,015	1,230	962.0	569.4	221.3	75.9	45.8	40.2
Harvest periods												
Last month	39.9	55.5	155.1	426.4	433.5	370.1	158.4	40.9	22.0	13.0	10.8	16.4
Last two months	56.3	95.4	210.6	581.5	859.9	803.6	528.5	199.3	62.9	35.0	23.8	27.2
Thunderstorm probability at harvest (%)	2.3	4.7	10.3	16.3	22.6	24.5	15.0	3.5	0.3	0	0.3	0.6

Source: Tables 1-8.

Table 11. Summary of environmental data for four month crop planted in month indicated, Kaohsiung, Taiwan, ROC.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Radiation (cal/cm^2)												
Whole crop	1,333	1,486	1,501	1,538	1,485	1,463	1,466	1,387	1,293	1,162	1,144	1,186
Last month	389	411	362	376	336	389	365	297	242	258	347	339
Temperature (^{o}C)												
Maximum	24.5	27.2	27.8	28.2	28.2	28.2	28.2	27.9	27.5	25.7	23.2	21.7
Minimum	18.6	19.2	21.7	24.5	27.2	27.5	25.7	23.2	20.1	18.6	18.6	18.6
Typhoon probability (%)												
Whole crop	0	5	10	25	45	40	35	20	0	0	0	0
Last two months	0	5	10	20	35	20	0	0	0	0	0	0
Last month	0	5	5	15	20	0	0	0	0	0	0	0
Precipitation (mm)												
Whole crop	122.6	266.9	676.9	1,080.5	1,385.1	1,388.4	1,002.9	591.4	234.3	86.7	62.2	80.1
Harvest periods												
Last month	55.5	155.1	426.4	433.5	270.1	158.4	40.9	20.0	13.0	10.8	16.4	39.9
Last two months	-	-	-	-	-	-	-	-	-	-	-	-
Thunderstorm probability at harvest (%)	4.7	10.3	16.3	22.6	24.5	15.0	3.5	0.3	0	0.3	0.6	2.3

Source: Tables 1-8.

Table 12. Summary of environmental data for five month crop; planted month indicated, Kaohsiung, Taiwan, ROC.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Radiation (cal/cm²)												
Whole crop	1,747	1,848	1,877	1,874	1,874	1,828	1,763	1,629	1,511	1,509	1,483	1,575
Last month	411	362	376	336	389	365	297	242	258	347	339	389
Temperature (°C)												
Maximum	27.2	27.8	28.2	28.2	28.2	28.2	28.2	27.9	27.5	25.7	23.2	21.7
Minimum	18.6	19.2	21.7	24.5	27.2	25.7	23.2	20.1	18.6	18.6	18.6	18.6
Typhoon probability(%)												
Whole crop	5	10	25	45	45	40	35	20	0	0	0	0
Last two months	5	10	20	35	20	0	0	0	0	0	0	0
Last month	5	5	15	20	0	0	0	0	0	0	0	0
Precipitation (mm)												
Whole crop	277.7	693.3	1,110.4	1,440.6	1,543.5	1,429.3	1,024.9	604.4	245.1	103.1	102.1	135.
Harvest periods												
Last month	155.1	426.4	433.5	370.1	158.4	40.9	22.0	13.0	10.8	16.4	39.9	55.5
Last two months	210.6	581.5	859.9	803.6	528.5	199.3	62.9	35.0	23.8	27.2	56.3.	95.4
Thunderstorm probability at harvest (%)	10.3	16.3	22.6	24.5	15.0	3.5	0.3	0	0.3	0.6	2.3	4.7

Source: Tables 1-8.

After the acceptable planting months for each parameter are recorded for a given crop the best planting options can be determined. This part of the procedure is very subjective, but a feel for which are the most important boundary conditions is gained fairly quickly. This is, of course, assuming that not all conditions can be satisfied in a given planting month, which is often the case. For example, the maximum solar radiation for a two month crop of heat sensitive Chinese cabbage in Kaohsiung will be obtained by planting in April (Tables 9 and 13). However, the temperature criteria can not be met in an April planting. March is the nearest planting month which satisfies the temperature constraint and has relatively high solar radiation. Planting in March also satisfies the typhoon, precipitation, and thunderstorm criteria. Therefore, this has been selected as the number one planting option for early maturity heat sensitive Chinese cabbage in Kaohsiung. A February planting has slightly less solar radiation (Table 9) and meets all other boundary criteria, thus it has been designated the second best planting month. A January planting has less than the desired solar radiation, but after examining planting options in other months it was selected as the third best planting month for early maturing heat sensitive Chinese cabbage in Kaohsiung. A similar procedure was carried out to identify the best three planting months for early maturing heat tolerant Chinese cabbage in Kaohsiung (Table 13) and for other crops (Table 14, 15, 16, 17, 28).

OPTIMAL CROPPING PERIODS

The optimal cropping periods for the 6 AVRDC crops and rice (Tables 19 & 20) were prepared based on the 3 best planting options in Tables 13-18. The added growing opportunity afforded by heat tolerant Chinese cabbage, white potato and tomato is evident.

The dominant role of rice in local cropping systems is demonstrated when the local cropping pattern for soybeans is compared to the optimal periods derived from only environmental considerations (Table 20). The two best periods for growing soybean coincide with the two best rice planting periods. As a consequence the most fequently observed time for planting soybean in the Kaohsiung area is in the fall season, which corresponds with the third best planting option for soybean.

Additional instructive insights can be gained by comparing actual cropping patterns with the optimal periods, based on environmental constraints, in Tables 19 and 20. More environmental[e] or non-environmental parameters such as market price, insect populations, disease prevalence, etc., can be introduced to further refine the selection of the best cropping periods for individual crops. For reference the mean monthly price indices for the 6 vegetable crops have been included in Tables 19 and 20 following each cropping period (6). Various combinations of multiple

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[e]Some suggested additions are:

Monthly mean maximum and minimum temperatures, number of days with maximum temperature above 30°C (for heat tolerance screening), evaporation or water balance and days with strong winds (for crops sensitive to wind damage). (7)

Table 13. Evaluation of Kaohsiung boundary conditions for 2 month crop planted in month indicated.

CHINESE CABBAGE

Radiation (cal/cm²)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Whole crop												
HS ≥ 650[a] (M)		cccc	cccc	cccc	cccc	cccc	cccc	cccc	cccc	cccc		
HT ≥ 725 (H)			CCCC	CCCC[b]	CCCC	CCCC						
Temperature (°C)												
10 ≤ HS ≤ 25	cccc	cccc	cccc									
20 ≤ HT ≤ 30			CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	
Typhoon probability(%)												
≤ 5% whole crop	cCcC[d]	cCcC	cCcC	cCcC					cCcC	cCcC	cCcC	cCcC
0% last month	cCcC	cCcC	cCcC					cCcC	cCcC	cCcC	cCcC	cCcC
Precipitation(mm)												
Whole crop (M) ≤ 250	cCcC	cCcC	cCcC	cCcC					cCcC	cCcC	cCcC	cCcC
Thunderstorm probability at harvest (%)												
≤ 5%	cCcC	cCcC	cCcC						cCcC	cCcC	cCcC	cCcC
Best planting options[c]												
HS	3	2	1									
HT			1	3					2			

[a]Level determined arbitrarily after examination of radiation in Table 9 to delineate periods of moderate to high radiation. [b]Indicates highest reading in this month. [c]Ranked from 1→3. [d]Indicates conditions suitable for both HT and HS cultivars. Periods noted with letter are acceptable for given parameter for production of heat sensitive Chinese cabbage (c) or heat tolerant Chinese cabbage (C).
Source: Tables 1 and 9.

Table 14. Evaluation of Kaohsiung boundary conditions for 3 month crop planted in month indicated.

CHINESE CABBAGE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SPE	OCT	NOV	DEC
Radiation (cal/cm^2)												
Whole crop												
HS (M) $\geq$ 900	cccc	cccc	cccc	cccc	cccc	cccc	cccc	cccc	cccc	cccc		
HT (H) $\geq$ 1070		CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC				
Temperature (^{o}C)												
10 $\leq$ HS $\leq$ 25	cccc	cccc									cccc	cccc
20 $\leq$ HT $\leq$ 30			CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC	CCCC		
Typhoon probability(%)												
$\leq$ 5% whole crop	cCcC	cCcC	cCcC						cCcC	cCcC	cCcC	cCcC
0% last month	cCcC	cCcC					cCcC	cCcC	cCcC	cCcC	cCcC	cCcC
Precipitation (mm)												
Whole crop (M) $\leq$ 251	cCcC	cCcC	cCcC						cCcC	cCcC	cCcC	cCcC
Last month (M) $\leq$ 100	cCcC							cCcC	cCcC	cCcC	cCcC	cCcC
Thunderstorm probability at harvest (%)												
$\leq$ 5%	cCcC	cCcC						cCcC	cCcC	cCcC	cCcC	cCcC
Best planting options												
HS	1								2	3		
HT	3	2	1									

Source: Tables 1 and 10.

Table 15. Evaluation of Kaohsiung boundary conditions for 3 month crop planted in month indicated

WHITE POTATO

Radiation (cal/cm²)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Last month												
HS (M)		wwww	wwww	wwww	wwww		wwww	wwww				
HT (H) ≥ 350												
Temperature (°C)												
15 ≤ HS ≤ 20												wwww
15 ≤ HT ≤ 30	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW	WWWW
Typhoon probability(%)												
Whole crop ≤ 10	wwww	wwww	wwww	wwww					wwww	wwww	wwww	wwww
Last mont ≤ 5	wwww	wwww	wwww	wwww			wwww	wwww	wwww	wwww	wwww	wwww
Precipitation (mm)												
Whole crop (M) ≤ 251	wwww	wwww	wwww						wwww	wwww	wwww	wwww
Thunderstorm probability at harvest (%)												
≤ 5	wwww	wwww						wwww	wwww	wwww	wwww	wwww
Best planting options												
HS												1
HT		1	2	3								

Source: Tables 1 and 10.

Table 16. Evaluation of Kaohsiung boundary conditions for 3 month crop planted in months indicated.

MUNGBEAN/SOYBEAN

Radiation (cal/cm^2)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MB Whole crop (H) $\geq$ 1070		MMMM	MMMM	MMMM	MMMM	MMMM	MMMM	MMMM				
SB Last month (H) $\geq$ 350		SSSS	SSSS	SSSS	SSSS		SSSS	SSSS				
Temperature (^{o}C)												
MB 20 $\leq$ MB $\leq$ 35			MMMM	MMMM	MMMM	MMMM	MMMM	MMMM	MMMM	MMMM		
SB 15 $\leq$ SB $\leq$ 30	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS	SSSS
Typhoon probability (%)												
Whole crop $\leq$ 5	SMSM	SMSM	SMSM						SMSM	SMSM	SMSM	SMSM
Last two months 0	SMSM	SMSM						SMSM	SMSM	SMSM	SMSM	SMSM
Precipitation (mm)												
Whole crop (M) $\leq$ 251	SMSM	SMSM	SMSM						SMSM	SMSM	SMSM	SMSM
Last month (L) $\leq$ 65	SMSM	SMSM						SMSM	SMSM	SMSM	SMSM	SMSM
Thunderstorm probability at harvest (%)												
$\leq$ 1									SMSM	SMSM	SMSM	SMSM
Best planting option												
Mungbean			1				3	2				
Soybean		1	2						3			

Source: Tables 1 and 10.

Table 17. Evaluation of Kaohsiung boundary conditions for 4 month crop planted in months indicated. Soybean (S), Sweet Potato (E), Rice (R)

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Radiation (cal/cm²)													
Last month (H) ≥ 350		XXXX	XXXX	XXXX	XXXX		XXXX	XXXX[a]					
Temperature (°C)													
15 ≤ S ≤ 30 10 ≤ E ≤ 35 15 ≤ R ≤ 35		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
Typhoon probability(%)													
Whole crop	S ≤ 5	SSSS	SSSS							SSSS	SSSS	SSSS	SSSS
	E ≤ 25	EEEE	EEEE	EEEE	EEEE				EEEE	EEEE	EEEE	EEEE	EEEE
	R ≤ 65	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR
Last two month	S = 0	SSSS						SSSS	SSSS	SSSS	SSSS	SSSS	SSSS
	E ≤ 20	EEEE	EEEE	EEEE	EEEE		EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
	R ≤ 15	RRRR	RRRR	RRRR				RRRR	RRRR	RRRR	RRRR	RRRR	RRRR
Last month	R ≤ 5	RRRR	RRRR	RRRR			RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR
Precipitation (mm)													
Last month													
Soybean (L)	≤ 65	SSSS						SSSS	SSSS	SSSS	SSSS	SSSS	SSSS
Sweet potato (M)	≤ 160	EEEE	EEEE				EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
Rice (M)	≤ 160	RRRR	RRRR				RRRR	RRRR	RRRR	RRRR	RRRR	RRRR	RRRR
Thunderstorm at harvest													
S	≤ 1								SSSS	SSSS	SSSS	SSSS	SSSS
E & R	≤ 15						ERER	ERER	ERER	ERER	ERER	ERER	ERER
Best planting option													
Soybean		1	2							3			
Sweet potato		2	1	3									
Rice		2	1					3					

[a]X applied to all crops. Source: Tables 1 and 11.

Table 18. Evaluation of Kaohsiung boundary conditions for 5 month crop planted in months indicated.
SWEET POTATO (E), HEAT SENSITIVE TOMATO (t), HEAT TOLERANT TOMATO (T)

Radiation (cal/cm²)		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Whole crop (H)	1800		XXXX	XXXX	XXXX	XXXX	XXXX						
Temperature (°C)													
$10 \leq E \leq 35$		EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
$15 \leq t \leq 25$												tttt	tttt
$15 \leq T \leq 35$		TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT
Typhoon probability (%)													
Whole crop	$E \leq 25$	EEEE	EEEE	EEEE					EEEE	EEEE	EEEE	EEEE	EEEE
	$t \leq 5$	tttt								tttt	tttt	tttt	tttt
	$T \leq 5$	TTTT								TTTT	TTTT	TTTT	TTTT
Last two months	$E \leq 20$	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
	$t = 0$					tttt	tttt	tttt	tttt	tttt	tttt	tttt	tttt
	$T = 0$					TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT
Precipitation (mm)													
Whole crop													
E (H)	≤ 1000	EEEE	EEEE						EEEE	EEEE	EEEE	EEEE	EEEE
T and t (M)	≤ 500	tTtT								tTtT	tTtT	tTtT	tTtT
Last Month (M) E	≤ 160	EEEE				EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
Last two month (M) T,t	≤ 200						tTtT	tTtT	tTtT	tTtT	tTtT	tTtT	tTtT
Thunderstorm probability													
at harvest (%) E	≤ 15	EEEE				EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE	EEEE
T,t	≤ 1							tTtT	tTtT	tTtT	tTtT	tTtT	tTtT
Best planting option													
Sweet potato													
Tomato	HS	2	1	3									
	HT	1				3	2					1	2

Source: Tables 1 and 12.

cropping sequences can be explored using the data in Tables 19 and 20. Promising patterns can then be evaluated in the field.

The object of this publication is to illustrate a method of deriving the best production periods for given crops from minimal amount of environmental information. The required data can generally be found for most locations, even in the tropics. Where exact data is lacking the relative magnitude or pattern of the annual fluctuations in the selected parameters can be used to perform the same type of analysis described in this paper. Suggestions for improving the analytical techniques and their explanations would be appreciated by the author.

Table 19. Optimal cropping periods for Chinese cabbage, White potato, and Mungbean, Kaohsiung, Taiwan, ROC.

Crop: Crop length (mo.)	Crop: Type	Planting option rank	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Chinese cabbage														
2	HS[a]	1			cccccccccc (95)[c]									
2	HS	2		cccccccccc (62)										
2	HS	3	cccccccccc (40)											
2	HT[b]	1		CCCCCCCCC (95)										
2	HT	2									CCCCCCCCC (113)			
2	HT	3				CCCCCCCCC (135)								
3	HS	1	cccccccccccccccc (62)											
3	HS	2									cccccccccccccccc (92)			
3	HS	3										cccccccccccccccccccc (46)		
3	HT	1			CCCCCCCCCCCCCCCCC (135)									
3	HT	2		CCCCCCCCCCCCCCCCC (95)										
3	HT	3	CCCCCCCCCCCCCCCCCC (62)											
White potato														
3	HS	1	wwwwwwwwwww (70)											
3	HS	2	NONE											
3	HS	3	NONE											
3	HT	1		WWWWWWWWWWWWWWWWWW (73)										
3	HT	2			WWWWWWWWWWWWWWWWWW (80)									
3	HT	3				WWWWWWWWWWWWWWWW (95)								
Mungbean														
3	-	1			MMMMMMMMMMMMMMMMM (107)									
3	-	2								MMMMMMMMMMMMMMMM (97)				
3	-	3							MMMMMMMMMMMMMMMM (95)					

[a]HS = Heat sensitive. [b]HT = Heat tolerant. [c]Relative price index for harvest month (s) shown in ( ) following cropping period. (mean 1972-1976 data). Source: Tables 1 and 13-16 & reference (8).

Table 20. Optimal cropping periods for soybean, rice, sweet potato and tomato, Kaohsiung, Taiwan, ROC.

Crop length	Crop type	Planting option rank	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Soybean														
3	early	1		SSSSSSSSSSSSS (97)[a]										
3	early	2			SSSSSSSSSSSSSS (99)									
3	early	3									SSSSSSSSSSSSSSS (99)			
4	late	1	SSSSSSSSSSSSSSSSSSS (97)											
4	late	2		SSSSSSSSSSSSSSSSSSSS (99)										
4	late	3							SSSSSSSSSSSSSSSSSSS (105)					
Rice														
4	-	1		RRRRRRRRRRRRRRRRRR										
4	-	2	RRRRRRRRRRRRRRRRRRR											
4	-	3							RRRRRRRRRRRRRRRRRR					
Sweet potato														
4	early	1		EEEEEEEEEEEEEEEEE (95)										
4	early	2	EEEEEEEEEEEEEEEEEEE (99)											
4	early	3			EEEEEEEEEEEEEEEEE (96)									
5	late	1		LLLLLLLLLLLLLLLLLLLLLLLL (96)										
5	late	2	LLLLLLLLLLLLLLLLLLLLLLLL (96)											
5	late	3			LLLLLLLLLLLLLLLLLLLLLLLL (93)									
Tomato														
5	HS	1	tttttttttttt (92)										tttttttt	
5	HS	2	tttttttttttttttt (76)										tttt	
5	HS	3		NONE										
5	HT	1	TTTTTTTTTTTTTTTTTTTTTTTT (64)											
5	HT	2						TTTTTTTTTTTTTTTTTTTTTTTTTTT (123)						
5	HT	3					TTTTTTTTTTTTTTTTTTTTTTTTTTT (134)							

[a]Relative price index 1972-1976 in Taiwan for harvest month(s) shown in ( ). Source: Tables 1 and 16-18 and reference (8).

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