CREDIT TO GIVE FOR AN IRRIGATION WHEN SCHEDULING IRRIGATIONS*

J. C. Wilcox
Member CSAE
Canada Department of Agriculture Research Station
Summerland, British Columbia

INTRODUCTION

In scheduling of irrigations it has been customary (1, 2, 3, 4) to credit the soil moisture balance sheet with the depth of irrigation water received and retained by the soil. This depth is usually calculated as (a) a stated percentage of available soil moisture to effective root depth, or (b) the depth of evapotranspiration occurring during an irrigation interval. In practice, these two methods should give essentially the same answer. Credit for an irrigation is entered at the start of the irrigation (2).

As previously reported (5), very low balances and soil moisture contents were found in the latter half of an orchard being irrigated. Before each irrigation was started the balance at the first setting was allowed to lessen to a value representing about 50% available moisture. At semi-arid sites this usually produced balances of less than 50% available water at the last setting of the line, sometimes as low as 20%. Excessive drying in the second half of the orchard was found to be caused by fluctuations in the weather. The optimum range of soil moisture in orchards was found to be between 100% and about 40% available water.

At the Summerland Station, tests made in orchards (7) indicated that the credit depth for irrigation might safely be reduced below 100% of the evapotranspiration. It is the purpose of this paper to report the results of an investigation into the effects of reducing the credit depth on the soil moisture balance, the peak flow and the seasonal water requirements.

DEFINITIONS OF SOME TERMS USED

Credit depth. Credit to give on the balance sheet for each irrigation, expressed in inches. In established orchards the same credit is given at every irrigation. It does not include water wasted during an irrigation.

Irrigation interval. The number of days between the start of an irrigation at any one spot and the start of the next irrigation at the same spot. The interval equals irrigation cycle time plus layoff time.

Safe interval. The maximum irrigation interval that can be allowed in the heat of the summer without impairing plant growth or yield because of lack of soil moisture.

Peak evapotranspiration (peak ET). The greatest total ET in inches that occurs during a safe interval. It is equal to 40% of the available water, so that about 60% available water is present in the soil at the first setting just prior to irrigating. Except where otherwise stated, the peak ET is that determined during the year of use.

Schedule balance. The balance in inches at the end of each day after credit has been given for rain by established scheduling procedures (7). Because full credit can not always be given for rain, the schedule balance usually differs from the true soil moisture balance.

True balance. The balance in inches at any setting of the line when credit is given for rain up to field capacity. Of greatest interest in this report is the lowest true balance at the last setting of the line.

Seasonal net ET. Total ET for the irrigation season minus credit given for rain on the balance sheet. Dividing the seasonal net ET by the application efficiency factor gives the seasonal irrigation requirement.

Peak flow. As used here,

$$\text{peak flow in U.S. gpm per acre} = \frac{18.9 \times \text{credit depth}}{\text{safe interval}}$$

Use of this formula assumes steady use of water during each irrigation cycle. It represents the flow needed to meet the peak ET requirement only.

EXPERIMENTAL PROCEDURE

Daily ET in inches was determined by use of evaporimeters (6), and the peak ET for an irrigation interval was determined from daily ET values. Credit was given on the balance sheet for simulated irrigations, the values used being 1.00, 0.95, 0.90, 0.85 and 0.80 x peak ET for 40 site-year combinations at 17 sites and 0.70, 0.60 and 0.50 x peak ET for 10 of these combinations. Deductions for ET on the balance sheet were, however, always 1.00 x ET. Scheduling rules already established (6, 7) were used.

The effects of reducing the credit depth below 1.00 x peak ET were determined by applying the scheduling procedure to "natural" models, consisting of daily values of ET and rain already obtained as noted above. Half of the 40 combinations were at semi-arid sites, half at semi-humid sites. It was assumed that there were just enough sprinklers to irrigate within the safe interval, which was 10 days except where otherwise noted. The irrigation season was considered to be from May 1 to September 15. The effects of reducing the credit depth were determined on the following: length of interval, percentage of time spent irrigating, lowest true balance, seasonal net ET, and peak flow per acre.

RESULTS

Range of Values Obtained

A summary of the range of values obtained at the 17 sites is presented in Table I. The lowest true balances shown were the lowest of those occurring just prior to irrigation at the last setting of the sprinkler line.

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Effects of Credit Depth on Length Of Irrigation Interval

Some typical examples of length of irrigation interval as affected by credit depth are shown in Table II. Although the safe interval was 10 days in all cases, the shortest interval that occurred was often longer than 10 days. This was because actual intervals usually overlapped the peak ET period, causing layoff time between irrigations. The average interval was longer at semi-humid sites than at semi-arid sites, and in wet years than dry years. A reduction in the credit depth shortened the average interval and increased the number of irrigations. It increased the percentage of time of irrigation in almost direct proportion to the reduction in credit depth.

Effects on Lowest True Balance

In almost every case the lowest true balance occurred at the last setting of the sprinkler line. Occasional exceptions to this occurred at semi-humid sites during wet seasons.

The data in Table I suggest that reducing the credit depth from 1.00 to 0.90 x peak ET had little effect on the lowest balance. The correlations shown in Table III indicate more clearly just what the effects were. Correlations between credit depth and lowest balance were non-significant at credit depths of 1.00 to 0.90 x peak ET, highly significant at credit depths of 1.00 to 0.85 x peak ET, and much higher still at credit depths below either 0.90 or 0.85 x peak ET.

The effects of the balance at the first setting on that at the last setting are also shown in Table III. As long as the balance at the first setting was not below 56% available water, the regression coefficient of the balance at the last setting was negligible. The 56% value represents a 44% deficit of available water, as compared with the 40% that is considered to be safe at time of starting to irrigate. Only when the credit depth was low enough to cause lower balances than 56% at the first setting did undesirably low balances occur at the last setting.

The frequency and amount of rain had variable effects on the lowest true balance (Table IV). At semi-arid sites this balance was almost as high in wet years as in dry years, as for example at Summerland in 1964 and 1967. Even in a wet year there was

TABLE I. RANGE OF VALUES OBTAINED IN IRRIGATION SEASON*

Parameter	Minimum	Maximum	Mean
Total ET, inches	11.1	27.9	18.2
Total rain, inches	2.0	10.3	5.1
Lowest true balance, %			
First setting, 1.00 x peak ET	58	74	63
Last setting, 1.00 x peak ET	35	69	50
Last setting, 0.90 x peak ET	42	65	50
Last setting, 0.50 x peak ET	-46	31	5
Seasonal net ET, inches	5.0	27.5	15.9
Peak ET, inches	1.01	3.24	1.98
Peak flow, U. S. gpm per acre	1.91	6.12	3.75
Shortest interval for 1.00 x peak ET, in days	10	27	12
Number of irrigations	4.0	10.7	8.0

* The lowest true balance is expressed as a percentage of the available water. The peak flow is that required to supply the peak ET.

TABLE II. EFFECTS OF CREDIT DEPTH ON LENGTH OF INTERVAL

Site and year	Credit depth in inches*	Successive irrigation intervals in days	% of time irrigating
Kersley 1966 (wet)	1.54	32--22--30--29--25	36
	1.46	32--20--20--18--35	40
	1.39	19--18--40--37--23	37
	1.31	20--17--38--38--22	38
	1.23	15--13--19--17--29--21--22	52
Kersley 1967 (dry)	1.71	20--14--15--13--16--18--14--13--15	65
	1.62	19--14--14--13--15--13--17--14--19	65
	1.54	18--15--11--11--17--13--16--10--12--15	72
	1.45	18--14--10--11--10--15--16--13--12--18	74
	1.37	17--15--10--10--10--13--12--14--10--12--15	80
Summerland 1964 (wet)	1.71	16--15--23--14--11--11--22--24	59
	1.62	15--15--22--13--10--12--19--12--20	65
	1.54	15--13--23--10--11--13--14--14--24	66
	1.45	14--13--18--11--13--10--10--17--11--21	72
	1.37	13--13--16--13--13--10--10--11--14--23	74
Summerland 1967 (dry)	2.41	22--18--16--14--12--11--12--10--12--11	72
	2.29	21--18--12--14--11--13--11--10--11--15	74
	2.17	20--17--12--14--11--12--10--10--10--11	80
	2.05	19--17--11--13--12--11--10--10--10--10--13	83
	1.93	18--16--11--12--11--10--10--10--10--10--10--11	86

* The safe interval was 10 days at all sites, and the credit depth at each site ranged from 1.00 to 0.80 x peak ET.

usually a period as long as four weeks with little or no rain. At the semi-humid sites, however, rain was sometimes frequent enough and heavy enough to keep the true balance at or above 60% available water, even with as short a safe interval as 10 days.

Increasing the safe interval from 10 days to 20 days had no consistent effect on the relation between the credit depth and the lowest true balance (Table V). Increasing the safe interval did, however, produce a greater relative increase in peak ET at semi-arid sites than at semi-humid sites. This was because little if any rain fell during 20-day peak intervals at semi-arid sites, while substantial amounts fell during 20-day peak intervals at semi-humid sites.

Effects on Seasonal Net ET Using Peak ET Determined in Same Year

At most sites, reducing the credit depth below 1.00 x peak ET had almost no effect on the seasonal net ET (Table IV). This was because the daily debit for ET on the balance sheet was always the ET for the day concerned irrespective of the credit depth used. At some semi-humid sites, however, there was some increase in net ET with decreasing credit depth. This was caused by a reduction in average length of irrigation interval, hence a decrease in the credit given for rain.

The peak flow as calculated lessened proportionately with the reduction in credit depth (Table IV). This was because a constant safe interval of 10 days was used for all credit depths.

Effects of Applying Highest Peak ET Recorded in Any Year To Data For All Years

Thus far in this paper the peak ET applied in any one year has been the peak ET determined that same year. This has helped to understand some of the principles involved. It is not a practical procedure, however, as the peak ET for the year is not known until the year's records have been obtained. In British Columbia (7) the highest peak thus far obtained in any year is applied to all years.

Comparisons of these two methods of using peak ET are shown in Table VI. At one semi-arid site, 10 years of records showed that the lowest true

TABLE III. SOME CORRELATIONS WITH LOWEST TRUE BALANCE AT LAST SETTING

Pairs used in correlations	n	r	Regression coefficient
A. Lowest balance at last setting x credit depth as a proportion of peak ET.			
All pairs	229	+0.65**	+160
Credit depth 1.00 to 0.90 x peak ET	117	+0.07	+ 25
Credit depth less than 0.90 x peak ET	112	+0.73**	+236
Credit depth 1.00 to 0.85 x peak ET	156	+0.33**	+ 29
Credit depth less than 0.85 x peak ET	73	+0.73**	+364
B. Lowest balance at last setting x lowest balance at first setting.			
All pairs	229	+0.92**	+0.98
Credit depth 1.00 to 0.90 x peak ET	117	+0.24*	+0.08
Credit depth less than 0.90 x peak ET	112	+0.95**	+0.96
Lowest balance at first setting higher than 56% available water	174	+0.28*	+0.09
Lowest balance at first setting lower than 56% available water	55	+0.95**	+1.02

* P = between 0.05 and 0.01
**P = less than 0.01

TABLE IV. SOME EFFECTS OF LOCATION, YEAR AND CREDIT DEPTH ON TRUE BALANCE, SEASONAL NET ET AND PEAK FLOW*

Site and year	Credit depth in inches	Lowest true balance		Seasonal net ET in inches	Peak flow in U. S. g.p.m. per acre
		First setting %	Last setting %		
Kersley 1966 (wet)	1.54	74	69	7.53	2.91
	1.46	63	51	7.57	2.76
	1.39	68	53	6.95	2.63
	1.31	68	57	6.68	2.48
	1.23	60	62	8.71	2.33
Kersley 1967 (dry)	1.71	57	48	14.65	3.23
	1.62	59	42	14.50	3.06
	1.54	58	46	14.79	2.91
	1.45	58	41	14.64	2.74
	1.37	54	42	14.80	2.59
Summerland 1964 (wet)	1.71	58	41	13.83	3.23
	1.62	58	37	13.81	3.06
	1.54	58	42	13.90	2.91
	1.45	56	42	14.10	2.74
	1.37	49	42	13.88	2.59
Summerland 1967 (dry)	2.41	59	40	22.98	4.55
	2.29	58	41	23.21	4.33
	2.17	57	44	23.01	4.10
	2.05	52	35	23.09	3.87
	1.93	46	33	22.90	3.65

*The safe interval was 10 days at all sites, and the credit depth lessened progressively at each site from 1.00 x peak ET to 0.80 x peak ET. The lowest true balance is expressed in per cent of available water. The peak flow is that required to supply the peak ET.

balance and the seasonal net ET averaged about the same by either method. Use of the highest (1967) peak ET for all years, however, increased both peak flow and irrigation interval by about 10%, and reduced the time spent in irrigating by about 10%. The peak flow and the time spent in irrigating were practically the same at 0.90 x peak ET using 1967 peak ET as at 1.00 x peak ET using the peak ET for each year.

Only three years' records were available at semi-humid sites, so the highest peak ET (in 1967) was applied to the other two years (1966 and 1968). As compared with use of peak ET for each year, use of the highest peak ET increased the lowest true balance in variable degree, reduced the seasonal net ET by about 9%, increased the peak flow by about 15%, and reduced the time spent in irrigating by 20 to 25% (Table VI). Use of the 1967 peak ET increased the layoff time, hence increased the credit for rain, which in turn affected the seasonal net ET. The peak flow and the time spent in irrigating were about the same at 0.80 to 0.85 x peak ET using 1967 peak ET as at 1.00 x peak ET using the peak ET for each year.

DISCUSSION

The credit depth was lowered from 1.00 to 0.90 x peak ET with little if any reduction in the lowest true balance. An examination of the balance sheets revealed why. For one thing, actual irrigation intervals usually overlapped the peak interval. Even when the actual interval coincided with the peak interval at the first setting, no serious reduction in the balance occurred. It is true, a small and temporary reduction in the balance occurred at the first setting, but this eliminated the possibility of the interval at the last setting coinciding with the peak interval. When this latter did occur, the effect on the lowest true balance was negligible.

It was found that the shortest irrigation interval was often much longer than the safe interval (Table II). This was especially true in wet years at semi-humid sites, but also occurred in dry years at semi-humid sites and in wet years at semi-arid sites. Application to all years of the highest peak ET obtained in any one year increased the length of the shortest interval still more. A valid question,

TABLE V. EFFECTS OF LENGTH OF SAFE INTERVAL ON LOWEST TRUE BALANCE AT LAST SETTING

Type of site and years	No. of sites averaged	Safe interval in days	Peak ET in inches	Lowest true balance at following credit depths*				
				1.00	0.95	0.90	0.85	0.80
Semi-arid (1966, 1967)	4	10	2.47	47	50	48	49	42
		20	4.60	47	44	46	44	41
Semi-humid (1966, 1967)	4	10	1.60	59	54	51	52	51
		20	2.12	54	55	54	51	52

* The credit depth is expressed as 1.00 x peak ET to 0.80 x peak ET. The lowest true balance is expressed in per cent of available water.

TABLE VI. EFFECTS OF APPLYING HIGHEST ANNUAL PEAK ET TO DATA FOR ALL YEARS*

Peak ET used	Credit depth in inches	Lowest true balance	Seasonal net ET in inches	Peak flow in U.S. g.p.m. per acre	Interval in days	% of time irrigating
A. A semi-arid site (Summerland), 10-day safe intervals, 10-year averages (1958-1967).						
Separate peak ET for each year	2.14	47	23.1	4.05	16.1	62
	2.03	47	23.1	3.84	15.2	66
	1.92	48	23.2	3.64	14.5	69
	1.82	47	23.2	3.44	13.9	72
	1.71	47	23.3	3.24	12.8	78
1967 peak ET used for all years	2.41	47	23.0	4.55	17.8	56
	2.29	48	23.2	4.33	17.2	58
	2.17	48	23.0	4.10	16.1	62
	2.05	46	23.1	3.87	15.4	65
	1.93	48	22.9	3.65	14.5	69
B. 5 Semi-humid sites, 10-day safe intervals, 2-year averages (1966, 1968).						
Separate peak ET for each year	1.58	57	9.3	2.99	20.8	48
	1.50	56	9.4	2.84	20.0	50
	1.42	55	9.4	2.68	19.2	52
	1.34	54	9.6	2.53	17.9	56
	1.26	54	9.7	2.38	17.0	59
1967 peak ET used for both years	1.88	60	8.5	3.55	27.8	36
	1.79	59	8.6	3.38	27.0	37
	1.69	56	8.9	3.19	24.4	41
	1.61	57	9.1	3.04	22.7	44
	1.50	57	8.9	2.84	21.7	46

* The safe interval was 10 days in all cases. The credit depth ranged from 1.00 x peak ET to 0.80 x peak ET in each case. The lowest true balance is expressed as a percentage of the available water as determined in 1967.

then, is why should the safe interval not be increased at semi-humid sites? If this could be done the grower could take longer to irrigate and he would use fewer sprinklers and a lower peak flow. In a peak year, however, there might not be enough water applied to maintain the moisture content of the soil within the optimim range. In any case, retaining the same peak ET produces the same irrigation intervals and the same seasonal net ET irrespective of whether or not the safe interval is lengthened. There does not seem to be much point in making such a change.

It can be assumed for practical purposes that a specified soil texture has the same available moisture capacity for a specified crop irrespective of the location, and that the same holds true with the credit depth. This poses a difficulty in relating credit depth to peak ET and safe interval in different years. At Summerland, for example, the peak ET recorded for a 10-day interval was 2.41 inches in 1967 and 1.71 inches in 1964; hence the available moisture capacity would appear to be greater in 1967 than in 1964. It is obvious that data from the peak year should be used for determining relationships among available moisture capacity, credit depth, peak ET and safe interval.

This paper has not dealt with the deliberate incorporation of a calculated risk into the design of an irrigation system, that is, the risk of excessive soil drying in very hot years. Adopting such a procedure would not be justified unless the risk involved was more than offset by reductions in cost of equipment, water and labor. There should be no added risk if the highest known peak ET is reduced by 10% to obtain the credit depth. An irrigation system could well be designed by incorporating into it both a credit depth of 0.90 x peak ET and a cost-risk factor.

SUMMARY

Evapotranspiration (ET) and rainfall records were obtained at sites in British Columbia representing a wide range of summer climates, and were used in simulated irrigation studies by means of a scheduling technique. Credit for irrigation on the balance sheets was based on the peak ET for the interval concerned. Reducing this credit had little effect on the lowest balances until it was reduced below 0.90 x peak ET. Reducing it to 0.90 x peak ET lessened by 10% the depth of water per application, the peak flow per acre and the average length of the irrigation interval. On the other hand, it increased the number of irrigations and the time spent in irrigating. There were only minor effects on the seasonal net ET, hence on the seasonal irrigation requirement. It is concluded that use of a credit depth of 0.90 x peak ET shows good promise for practical use, especially if the peak ET of the hottest year recorded is applied to all years.

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EVALUATION OF A METHOD . . .

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program is a practical method of achieving optimum benefits from irrigation.

CONCLUSION

Evidence is presented that the irrigation scheduling program operated on an extension basis in southern Alberta will produce maximum crop yields at an operationally practical irrigation level. A base is presented by which the economic benefits of irrigation of four representative crops may be calculated.

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