IRRIGATION IN SKÅNE - ESTIMATED WATER NEEDS AND EFFECT ON WATER AVAILABLE TO CROPS

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June 1980
WP-80-112

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PREFACE

Water resource systems have been an important part of resources and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resources management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resources development alternatives aided by application of mathematical modelling techniques, to generate inputs for planning, design, and operational decisions.

During the year of 1978 it was decided that parallel to the continuation of demand studies, an attempt would be made to integrate the results of our studies on water demands with water supply considerations. This new task was named "Regional Water Management" (Task 1, Resources and Environment Area).

The paper is part of a collaborative study on water resources problems in Western Skåne, Sweden, pursued by IIASA in collaboration with the Swedish National Environment Protection Board and the University of Lund. The present paper looks at the agricultural demand for irrigation water. Irrigation is relatively new in the Skåne region but is on the increase, making estimation of potential needs important.

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Task Leader

ACKNOWLEDGEMENT

I would like to thank Lennart de Maré for searching out sources of information on irrigation practices in Skåne and for translations from the Swedish.

This study was supported in part with funds provided by the Volkswagen Foundation.

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1. INTRODUCTION

Irrigation is a recent development for Swedish agriculture. Extensive irrigation began in the 1970s, largely due to a series of dry summers in 1970-75 and the development of simple irrigation machines. Use is rapidly expanding, and agricultural water needs are likely to continue increasing in the near future. This is particularly true for Skåne, where the crop structure and the prevalence of relatively large farms make irrigation especially attractive.

The purpose of this report is two-fold:

- estimation of water needs in Skåne for supplementary irrigation of various crops; and
- estimation of the effects of supplementary irrigation on the total amount of water available to crops.

Estimates of these kinds are difficult to make in Skåne, for several reasons. First, there have been only about ten years of experience with irrigation in the area. Second, irrigation practices have changed over those years in terms of amount and frequency of application. Third, farmers are sometimes forced to use less water than they would like because water sources are not always able to provide sufficient supplies (Johansson and Klingspor, 1977). In short, there has been only limited experience with irrigation in Skåne--with the amounts of water required, or with the effect of irrigation on the total water available to crops. Estimation of potential water needs for supplementary irrigation cannot in this case be based on actual data.

In this report, the difficulties mentioned above are circumvented by using historical rainfall data in conjunction with a set of irrigation rules to simulate seventy-five years of irrigation for various crops. The irrigation rules used in this report were chosen to reflect as closely as possible the actual irrigation practices of farmers in the Skåne region, assuming an unlimited supply of water for irrigation. They are "rules of thumb" presently recommended to farmers.

Using the simulated irrigation data, estimates are made of the water required to allow full implementation of the present rough irrigation recommendations. Estimates presented in this report include the average, standard deviation, and range of seasonal water requirements, as well as the percentage of seasons requiring specific amounts of water. The effect of these irrigation schemes on the water available to crops--in terms of the average quantity, its variability from season to season, and the consistency of supply throughout the season--is also estimated. Estimates are made for all major crops grown in Sweden, whether presently irrigated or not. For crops not generally irrigated at present, estimates indicate the potential water requirements if irrigation is undertaken. The estimates are, to the author's knowledge, the only such complete published estimates of this sort for Skåne.

A major conclusion of this report is that, if farmers continue to use the rough "rules of thumb" described here, irrigation water needs in Skåne may be considerably higher than previously thought. Estimates of the amounts of water needed to fulfill these rules in a dry year are substantially higher than previous dry year estimates based on soil moisture irrigation rules. Estimated water needs are also higher than would be indicated by simple rainfall deficit measures--that is, the difference between rainfall and optimal water levels for crops.

Note that the irrigation rules used in this report, and presently recommended in Skåne, are intended to maximize, or at least increase, crop yields in practice, farmers may wish to maximize net income rather than crop yields alone. For an analysis of irrigation in Skåne including both costs and benefits see the paper by R. Anderson (1980).

2. IRRIGATION PRACTICES

The irrigation schemes used for simulation are based on recommendations from Rune Andersson (personal communication to L. de Maré, 1979) at the Malmohus County Board/Environmental Protection Unit (Lansstyrelsen, Malmohus lan/Naturvardsenheten) with some modifications suggested by W. Johansson (personal communication to L. de Maré, 1980) at the Sveriges Lantbruks-universitet (Swedish Agricultural University), Uppsala. The irrigation rules are also close to the recommendations made in two papers by H. Linnér (1977, 1979).

These irrigation schemes require only daily measurement of rainfall. More complicated rules can be devised, based for example on soil moisture, which match irrigation more closely to the true water needs of the crops. However, they require more sophisticated equipment. The "rule of thumb" application of irrigation water, as described in this report, is generally considered to be, today, the method most used by Swedish farmers (personal communication from L. de Maré, 1980). How estimates based on other rules differ from these is considered in a later section of the report.

Evapotranspiration in Skåne is roughly 3.5 mm per day in May-July and 2.5 mm per day in August and September. These figures are used in recommending the amount of water which should be available to crops: for clay soil, 35 mm per ten days in May-July, 25 mm per ten days in August and September; for sandy soil, 25 mm and 18 mm per seven days in May-July and August-September. Until recently the recommended amount was 35 mm/25 mm every ten days for both types of soil, but it is now felt that sandy soil requires water more frequently.

For sandy soil, the recommended irrigation schedule is as follows. If in a 7-day period there has been no rain, 25 mm (18 mm during August and September) of irrigation water are applied on the seventh day. If rainfall has amounted to x mm during this period, irrigation is postponed by x/3.5 days (x/2.5 days during August and September). At the end of the postponement period, if more rain has fallen, a second postponement is allowed, and so on. In this way, irrigation is delayed as long as the crops are receiving about 3.5 mm of water per day (2.5 mm during August and September). Decisions to irrigate or continue postponement are made at the end of each postponement period. However, any single postponement period is limited to a maximum value, regardless of previous rainfall. For the purposes of this report, the maximum single postponement is taken to be 10 days. The schedule for clay soil is the same, except that 35 mm (25 mm during August and September) are applied at 10-day intervals unless rainfall levels warrant a delay.

The irrigation schedules outlined above are used, in general, regardless of crop. However, the irrigation season (the period during which irrigation is considered important) varies by crop. For Skåne, the irrigation seasons for the major crops are, according to H. Linnér (personal communication to L. de Maré, 1980):

Crop	Irrigation Season
Grain	June 1 - July 15 (1.5 months)
Vegetable oil crops	May 16 - July 15 (2 months)
Potatoes	June 16 - August 31 (2.5 months)
Sugar beets	July 1 - Sept. 15 (2.5 months)
Harvested ley	May 16 - August 15 (3 months)
Grazing ley	May 16 - Sept. 15 (4 months)

Although garden products are an important crop in Skåne, it is difficult to make generalizations about irrigation techniques. Each product must be considered separately. For this reason, garden products are not included in this report. Note that, outside of garden products, the crops considered most worthwhile to irrigate in Skåne are potatoes and sugar beets. Irrigation of ley is becoming more important, however, and irrigation of grain also seems to be increasing (personal communication of W. Johansson to L. de Maré, 1980).

3. ESTIMATES OF IRRIGATION WATER NEEDS BY CROP

Irrigation requirements can be simulated by applying the irrigation schemes described in the last section to historical rainfall data. The simulation technique used for this report is quite simple and straightforward. For completeness, however, a short description follows. The daily rainfall data for a season are read into the computer. For sandy soil, starting with the first day of the irrigation season for the crop of interest, the simulation program sums rainfall for seven days. At this point the program must make a decision. If there was no rainfall during the seven days, the program records the seventh day as an irrigation day, and continues. If there was rainfall, then the total amount is divided by 3.5, (2.5 during August and September) and the result rounded to the nearest integer--this is the length of the postponement period. The program adds rainfall for the number of days in the postponement period, and then reaches another decision point, and so on. In this way, the program copies the operational irrigation rules described in the last section, and counts the number of days in each season on which irrigation is necessary. The amount of irrigation water needed is of course just the number of these days times the amount of water applied (18/25 mm for sandy soil, 25/35 mm for clay soil).

The amount of water required to fulfill the recommended irrigation pattern for each season and each crop is calculated as described above. In this report, water requirements refer to the amount of irrigation water that can be used by the crops, not the amount withdrawn from the source. It must be kept in mind that some losses will occur. In Skåne, losses will probably not exceed 10-15% and will usually be considerably less (Valegård, 1978).

The precipitation data used in this report were collected in Lund by the Department of Geography at the University of Lund (Institutionen for naturgeografi, Lunds Universitet). They consist of daily rainfall records for the years 1900-1974. Ideally, rainfall records should be collected from individual farms. Failing this, it is assumed here that the Lund records are fairly representative (see map in Figure 1).

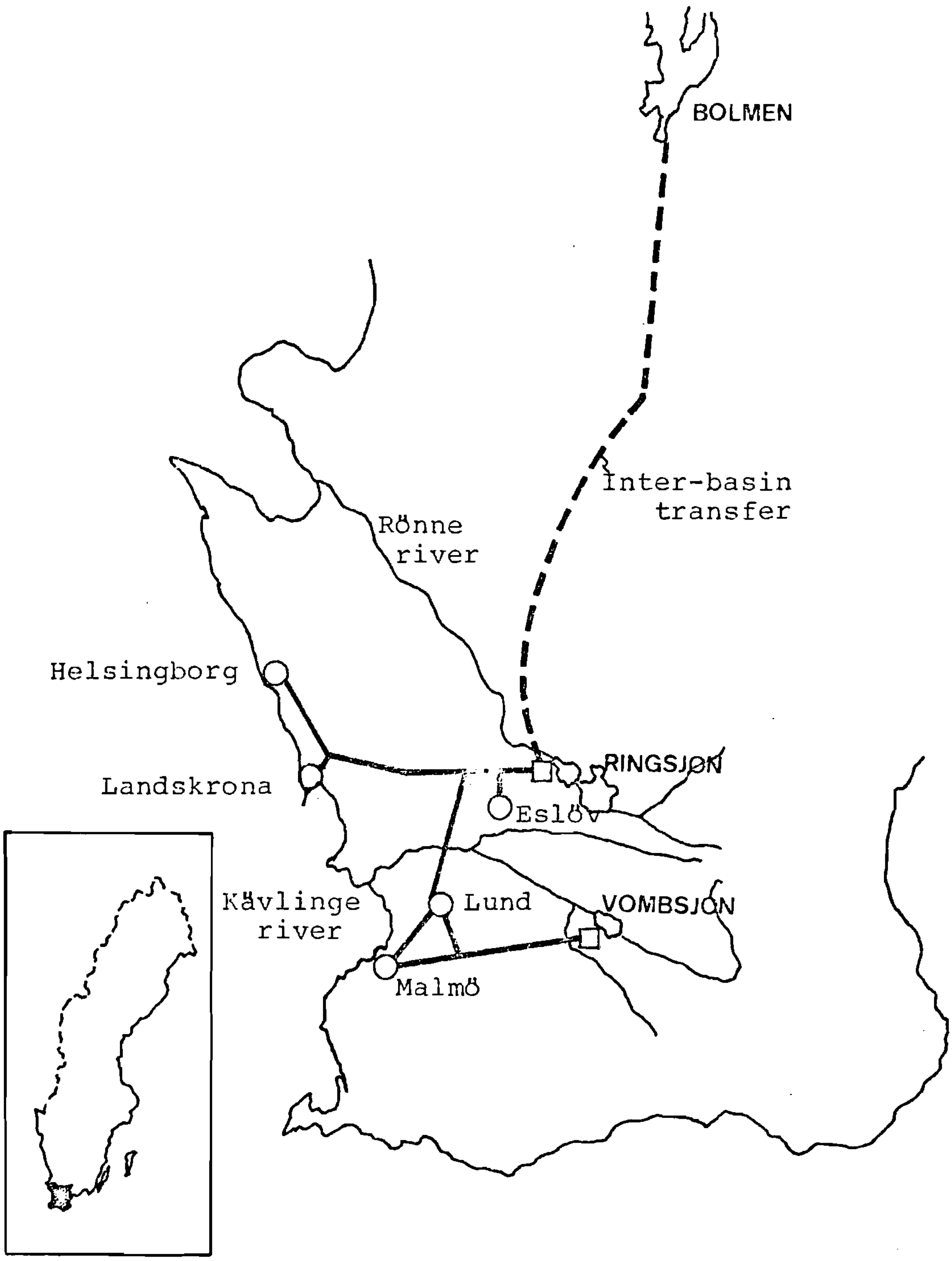

Figure 1. Study Area - Western Skåne, Sweden

Table 1 summarizes the results of simulating irrigation practices for the major crops in Skåne--grain, potatoes, sugar beets, vegetable oil, and ley. For each crop the soil type, irrigation season, and average seasonal irrigation water needs (with standard deviation) are tabled. The observed range of irrigation water needs (minimum and maximum values), and median values are also given. The median value may be of particular interest in this case, since it is an amount of irrigation water which may actually be required--half of all simulated seasons have irrigation water needs less than or equal to the median, half have needs greater than or equal to the median. On the other hand, since irrigation water is applied only in multiples of 18, 25, or 35 mm, the average water need is in general an amount that will not be exactly required in practice.

According to Table 1, grain crops will require, on average, about 90 mm of irrigation water per season, potatoes 99 mm, sugar beets 86 mm, vegetable oil 127 mm, harvested ley 161 mm, and grazing ley 184 mm. The excessive requirements for ley are due to the long irrigating season (3-4 months). Ranges of observed water requirements are 25-150 mm for grain, 18-179 mm for potatoes, 25-155 mm for sugar beets, 35-175 mm for vegetable oil, 70-235 mm for harvested ley, and 70-285 mm for grazing ley.

Table 2 presents, for each crop, the percent of seasons out of the 75 simulated years for which a given amount of irrigation water was required. This table provides information on how often a farmer may expect to have to provide particularly large (or small) amounts of irrigation water. For instance, potatoes will require 175-199 mm of irrigation water in 1% of all seasons, grazing ley will require 275-299 mm in 3% of all seasons.

4. COMPARISON TO OTHER ESTIMATES

How do the estimates from the last section compare with other recent estimates of irrigation water needs? A study of irrigation needs undertaken by Johansson and Klingspor in 1977 presents estimates of water needs for various crops in several regions of Sweden, including Skåne. Water needs are estimated for a "dry year" and for the year 1976 separately.

Table 1. Estimates of Irrigated Water Needs by Crop

Crop	Usual Soil Type	Irrigation season	Average Seasonal requirement	(Standard deviation)	Range	Median seasonal requirement
Potatoes	Sandy	June 16 - August 31 (2.1/2 months)	99 mm	(37)	18-179 mm	100 mm
Grain	Sandy	June 1 - July 15 (1.1/2 months)	88 mm	(28)	25-150 mm	100 mm
Grain	Clay	June 1 - July 15 (1.1/2 months)	90 mm	(24)	35-140 mm	105 mm
Vegetable oil	Clay	May 16 - July 15 (2 months)	127 mm	(31)	35-175 mm	140 mm
Sugar beets	Clay	July 1 - Sept. 15 (2.1/2 months)	86 mm	(32)	25-155 mm	85 mm
Ley (harvested)	Clay	May 16 - August 15 (3 months)	161 mm	(34)	70-235 mm	165 mm
Ley (grazing)	Clay	May 16 - Sept. 15 (4 months)	184 mm	(40)	70-285 mm	190 mm

Table 2. Percent of Seasons Requiring a Given Amount of Irrigated Water (based on 75 simulated seasons)

Crop	0- 24 mm	25- 49	50- 74	75- 99	100- 124	125- 149	150- 174	175- 199	200- 224	225- 249	250- 274	275- 299
Potatoes	1	5	21	20	25	17	8	1				
Grain (sandy soil)		5	11	31	33	19	1					
Grain (clay soil)		5	39	0	51	5						
Vegetable oil		1	7	0	35	41	0	16				
Sugar beets		8	33	29	21	7	1					
Ley (harvested)			1	1	7	35	17	16	19	4		
Ley (grazing)			1	0	3	13	28	16	17	15	4	3

The Johansson and Klingspor dry year estimates are based on irrigation rules designed to maintain optimal soil moisture for each crop. These rules were applied to meteorological data, including rainfall, from 1931-60 in each of several regions in Sweden. Estimates of water needs in each year were used to calculate the needs for a dry year (the separate yearly estimates do not appear to have been published). A dry year is taken to be that year requiring the fifth largest irrigation amount in the sequence of thirty years, 1931-60. For the 75 years of simulated data in this report, a dry year is, by this definition, that year with the twelfth largest irrigation requirement.

The Johansson/Klingspor estimates for 1976 appear to have been calculated from dry year estimates by reducing those estimates by amounts commensurate with the rainfall levels of 1976. Exactly how the reductions were calculated is not specified. No direct comparison with estimates presented in the last section was possible, because the Lund rainfall data did not include 1976. Instead, the irrigation rules specified in Section 1 were applied to daily rainfall data from Vombsjon to obtain estimates for 1976. The locations of the two rainfall measurement stations used by this study are shown on the map in Figure 1.

In Table 3 the Johansson/Klingspor estimates are compared to estimates based on the irrigation rules of this report. The dry year estimates for potatoes and sugar beets are very similar, but in all other cases the estimates from this report are much higher than the corresponding Johansson/Klingspor estimates.

In the case of ley, a large part of the discrepancy is due to the fact that Johansson and Klingspor reduced their estimates by around 30% because they felt that farmers often do not irrigate ley late in the season. Therefore the difference in estimates largely reflects how much more water is required if farmers do continue to irrigate ley throughout the season specified in Section 2.

Table 3. Estimates of Irrigated Water Needs
Compared to Johansson/Klingspor Estimates

Crop	Estimated dry year needs	Johansson/ Klingspor estimated dry year needs	Estimated 1976 needs (Vombsjon)	Johansson/ Klingspor estimated 1976 needs
Potatoes	136 mm	140 mm	154 mm	115 mm
Grain (sandy soil)	125	50-65	100	20-30
Grain (clay soil)	105	50-65	70	20-30
Vegetable oil	175	50-65	105	20-30
Sugar beets	120	110	120	95
Ley (harves-ted)	200	75-120	165	55-85
Ley (grazing)	225	160	190	115

Ley estimates from this report remain higher than the Johansson/Klingspor estimates, even after discounting the 30% reduction. And, except for the two cases mentioned, all other estimates are much higher. Why are the estimates so different?

For the dry year estimates the major difference in estimation lies in the irrigation rules adopted. Johansson and Klingspor use a sophisticated irrigation rule based on soil moisture. It is undoubtedly better at matching irrigation to the true water needs of the crops, but is unlikely to reflect what farmers actually do. The much higher water needs estimated under the "rule of thumb" irrigation schemes used by this report indicate that farmers should be encouraged to measure soil moisture, and use more sensitive rules for irrigation, such as those used by Johansson and Klingspor. The savings in irrigation water would be substantial.

It is difficult to say how much of the differences in 1976 estimates is due to the irrigation rules chosen, since it is unclear exactly how the Johansson/Klingspor estimates were calculated. However, for both sets of estimates we can say that the water needs under present "rule of thumb" irrigation practices are likely to be significantly higher than the Johansson/Klingspor estimates would indicate.

5. EFFECTS OF IRRIGATION ON WATER AVAILABLE TO CROPS

Crop yields depend on several aspects of water availability. Among these are the total seasonal quantity of water available and its distribution throughout the season. Farmers themselves are interested not only in crop yields, but also in the reliability of yields, which depends to a large extent, on the variability of water supply. So it is important to know how all these aspects of water availability are affected by irrigation. This section estimates, first, the effects of the irrigation schemes of Section 2 on several characteristics of total seasonal water supply, then the effects on distribution of water throughout the season.

5.1 Effects on Total Seasonal Water Quantities

How do the irrigation schemes described in Section 2 of this report affect total seasonal water supply--its average value, variance and the shape of its probability distribution? In terms of water supply, the crucial season will differ for each crop. We look at each crop separately, and take the crucial season to be the irrigation season (see Section 2). Seasonal totals without irrigation are, of course, simply the seasonal rainfall totals. Seasonal totals with irrigation include rainfall and irrigation totals. Irrigation totals are simulated as described in Section 2 of the report.

Table 4 summarizes the change in average value and standard deviation of the seasonal water available to crops when irrigation is used. The average values of total seasonal water available with irrigation are 1.5 to 2 times higher than without irrigation. For example, rainfall provides on average 176 mm per season for potatoes. Irrigation and rainfall together provide on average 274 mm per season.

The average quantities of water available for crops have been greatly increased. But just as important, variability in quantity of water available from season to season, as measured by the standard deviation, has been reduced. The change is striking--a reduction of between 26 and 41 percent.

In addition to knowing the changes made by irrigation in average values of the seasonal totals, it is helpful to know how irrigation changes the rate of occurrence of seasons with particularly low quantities of water available to crops--in fact, how irrigation changes the entire probability distribution of seasonal totals. Figure 2 shows histograms of seasonal water totals for each crop, with and without irrigation. The histograms make even clearer the differences discussed in the preceding paragraphs. In every case, the mean of the distribution of seasonal water totals has been significantly increased, and the spread of the distribution significantly reduced. Irrigation shifts the entire distribution to the right and reduces its spread, guaranteeing an acceptable minimum supply of water,

Table 4. Water Available to Crops, with and without Irrigation (in mm)

Crop	Irrigation Season	Water Available from Precipitation Alone		Water Available from Precipitation + Irrigation	
		Average in season	Standard (deviation)	Average in season	Standard (deviation)
Potatoes	16 June - 31 August	176	(56)	274	(33)
Grain (sandy soil)	1 June - 15 July	83	(34)	171	(24)
Grain (clay soil)	1 June - 15 July	83	(34)	173	(25)
Vegetable oil	16 May - 15 July	105	(36)	232	(22)
Sugar beets	1 July - 15 September	174	(51)	259	(34)
Ley (harvested)	16 May - 15 August	179	(49)	340	(32)
Ley (grazing)	16 May - 15 September	249	(60)	433	(37)

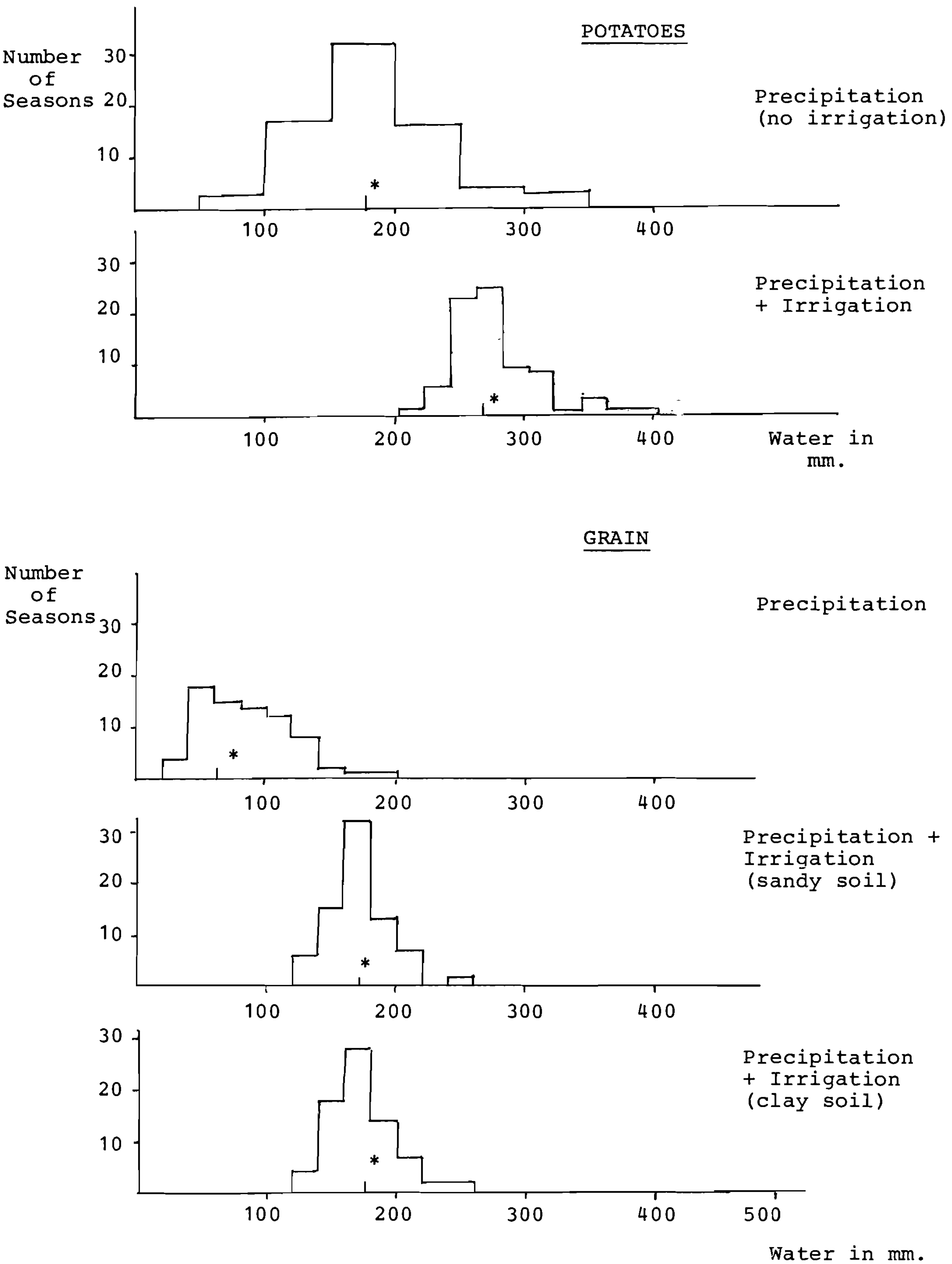

Figure 2. Seasonal Water Totals supplied to Crops, with and without irrigation (* Average water supply is ticked).

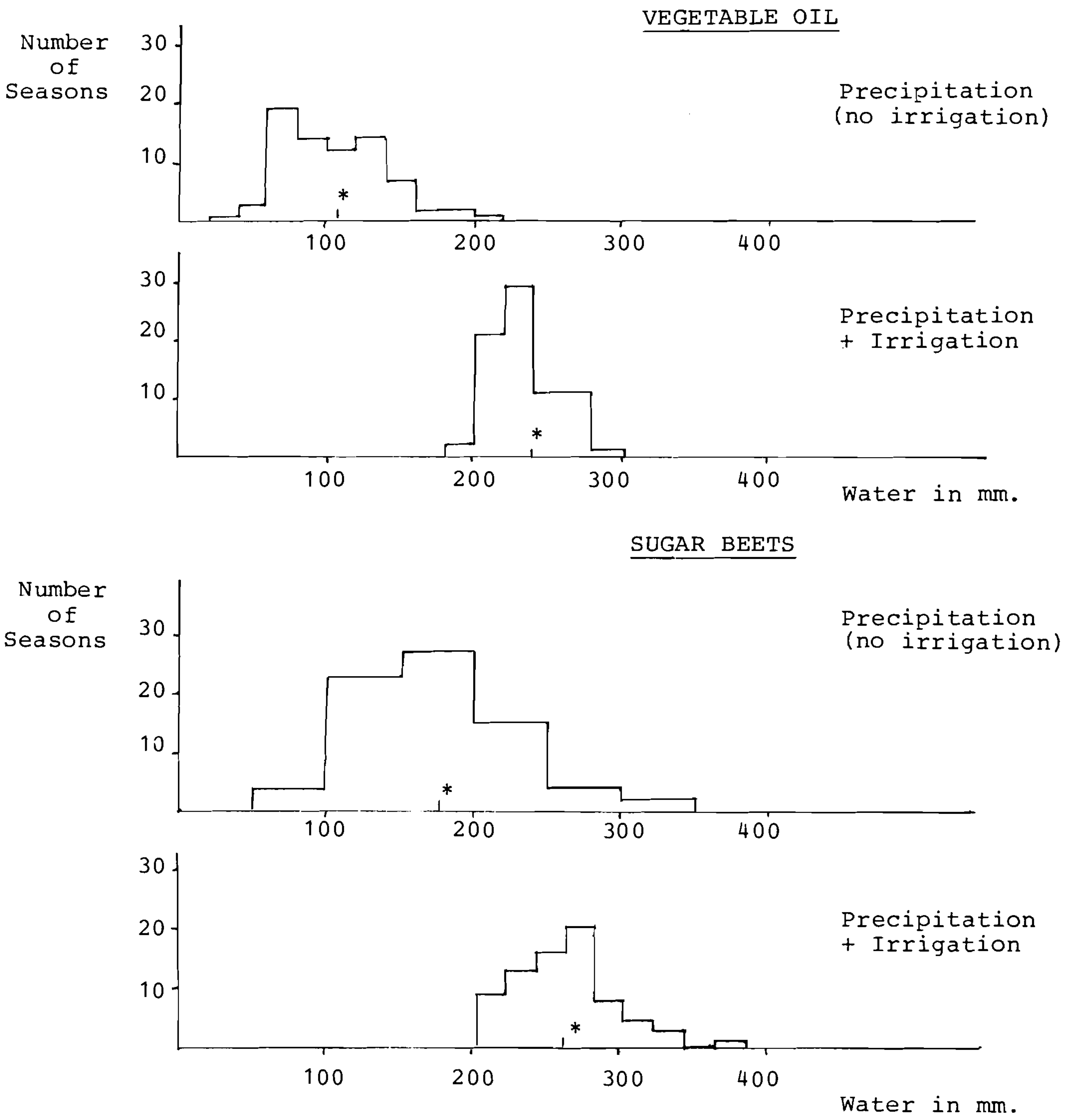

Figure 2. (contd.)

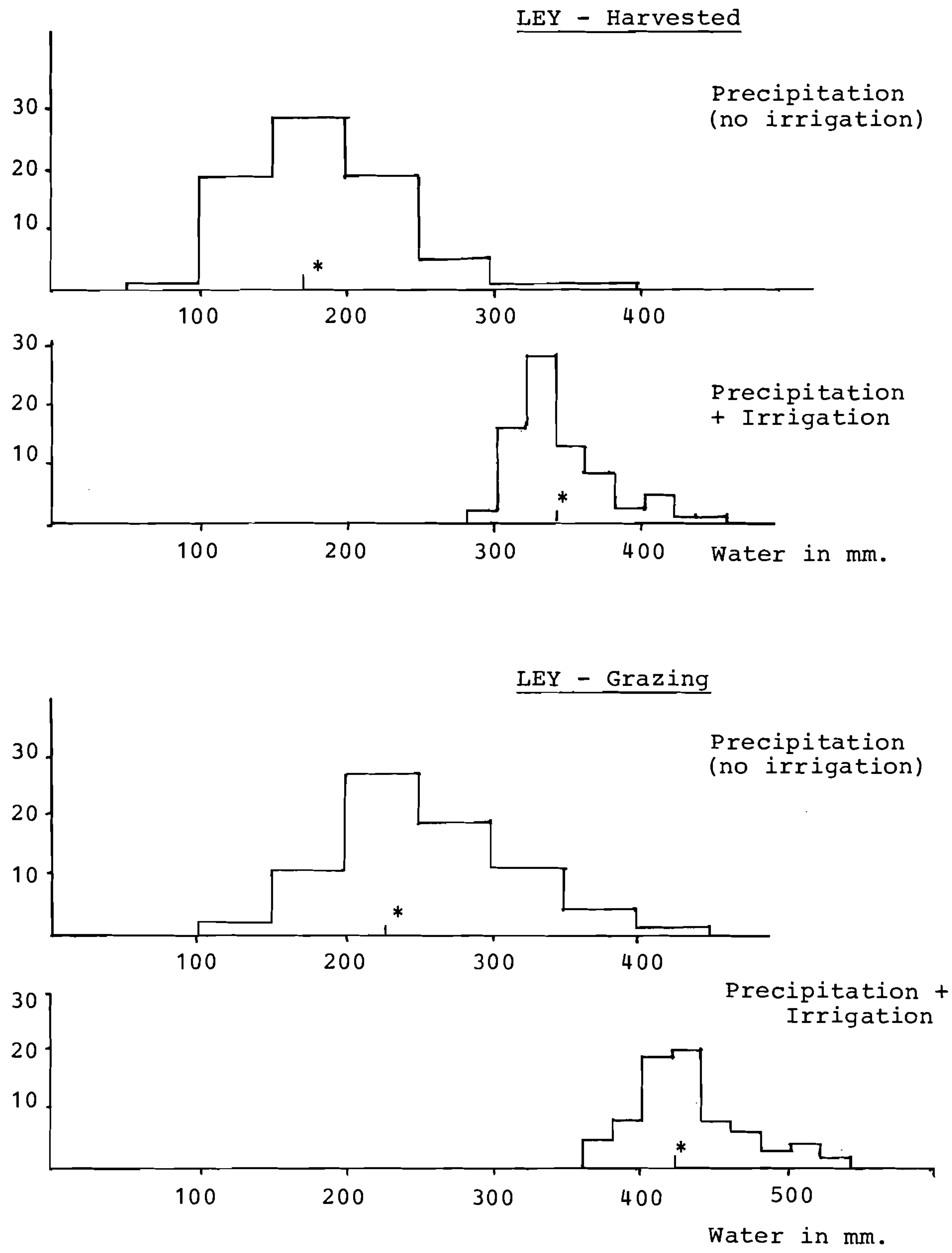

Figure 2. (contd.)

no matter how dry the season. In fact, for every crop considered, the minimum water supply with irrigation is greater than the average supply without irrigation.

5.2 Optimal Water Supply

In judging the effectiveness of the irrigation schemes, it would be helpful to know how the water supply with irrigation compares to some 'optimal' pattern of water supply. A study of irrigation in Sweden was done in 1977 by Johansson and Linnér. This study includes some estimates, for southern Sweden, of the optimal amounts of water needed during May, June, July, August, and September, for potatoes, ley, and spring grain. We compare these estimated optimal amounts with the average amounts provided by our irrigation schemes in each month. It is assumed, of course, that irrigation only takes place during the months specified by the irrigation schemes. So, for potatoes, irrigation will take place from June 16 to August 31. The average amounts of water available during other months will be just the average rainfall amounts.

The optimal and irrigation averages are shown in Table 5. With few exceptions, the water supplied by irrigation and rainfall together exceeds the optimal amounts. The excess is, in general, about 10-20 mm in each month that irrigation is applied. The present irrigation practices used in Skåne thus tend to oversupply water compared to optimal amounts, in terms of monthly quantities. This oversupply of irrigation water is to a large extent the necessary consequence of imperfect information about future rainfall, as explained below.

The optimal irrigation behavior of farmers with respect to total quantities of water applied (it is not necessarily optimal in other respects) would be to irrigate an amount equal to the rainfall deficit in any month. That is, irrigation should bring the total amount of water supplied to the optimal amount. Unfortunately, the optimal behavioral rule is not operational. It cannot be followed in practice because the farmer does not know what the total monthly rainfall will be until the end of the month--after his irrigation decisions have been made. He

Table 5. Optimal Monthly and Seasonal Water Needs Compared to Average Water Provided by Precipitation + Irrigation (in mm)

Crop		May	June	July	August	September	May – September
Potatoes:	Optimal	40-45	80-85	90-100	70-75	40-45	330-350
	Average precipitation + irrigation	42(R)	82	118	96	57(R)	395
Spring Grain:	Optimal	60-65	90-100	70-80	40-45	25-30	290-310
	Average precipitation + irrigation	42(R)	115	97	73(R)	57(R)	383
Ley:	Optimal	80-85	90-100	90-100	70-75	55-60	390-420
harves-ted:	Average precipitation + irrigation	85	110	118	86	57(R)	456
grazing:	Average precipitation + irrigation	85	110	118	97	69	479

Note: (R) indicates no irrigation is done in this period.

must protect himself against his lack of information, against the possibility of a very dry late month, and in so doing he will tend to overirrigate in comparison with optimal amounts.

To see why farmers will on average overirrigate, consider the following situation. Suppose there is an optimal amount of water, x, for a given time period, and assume the farmer must irrigate at least once before the end of the period (if he can wait until the end of the period to irrigate, lack of information creates no problem, and optimal levels can be met exactly). If the farmer irrigates an amount $y<x$, then there exists some probability that rainfall in the remainder of the period will exceed $(x-y)$ and the farmer will have overirrigated. On the other hand, there is no possibility of underirrigation because the farmer can make up any deficit on the last day of the period. The positive probability of overirrigation, no matter how small, forces average irrigation to be greater than the optimal level.

Even if farmers attempt to meet optimal water levels exactly they will tend to overirrigate. So it is not surprising that operational irrigation rules such as the one used in this report should overshoot optimal water levels. However, for some months and some crops (e.g. potatoes in July and August), the excess may be unacceptably high. Modification of the thumb rules suggested to farmers may be worthwhile.

Estimates of irrigation water needs are often based on the rainfall deficit (the difference between rainfall and optimal water amounts in some period, usually a month). The analyses of this section show that these estimates may not be satisfactory. They will in general underestimate actual needs, since they assume perfect knowledge of future rainfall.

5.3 Effects on Seasonal Distribution of Water

Judging the success of irrigation in terms of providing some optimal total water amounts is not entirely satisfactory. The total seasonal or monthly water available to crops is only one aspect of the water supply. Distribution of the total water over the season is at least as important. In fact, the philosophy of our irrigation schemes is not to provide a particular seasonal quantity, but rather to maintain a supply of about 3.5 mm per day of water to crops during their irrigation seasons (2.5 mm per day during August and September). How well do the irrigation regimes fulfill this goal?

Table 6 gives, for each crop, the average quantity of water supplied for each two-week period in its season. The target 3.5 mm per day corresponds to 52 mm for 15 days, 56 mm for 16 days, while 2.5 mm per day corresponds to 37.5 and 40 mm, respectively. It is clear from the table that the 3.5 mm per day target for May-July is met quite well--on average, 53-65 mm are supplied in each period. The irrigation schemes tend, however, to overshoot the 2.5 mm per day target for August and September, supplying 43-50 mm in each period. This may be due to the fact that postponement periods continuing into August from irrigation done in July are based on 3.5 mm per day.

Even for the 3.5 mm per day targets, the averages for the two-week periods are always somewhat high. This is another instance of the overirrigation phenomenon described in the last section. Here we are considering 52/56 mm to be optimal for a two-week period. Again, lack of precise future rainfall information encourages overirrigation. In this case the excess is minimal because the time periods are so short.

6. CONCLUSIONS

When considering irrigation in a region, it is important to estimate both potential irrigation water demands and potential effects of irrigation on the total amount of water available to crops. This may be difficult to do using observed data. If irrigation is new in the region or if irrigation practices have changed, there may be very little data available. Also, limitations on the water available for irrigation may make observed use figures misleading. In either case, the technique of using simulated irrigation data offers one useful way to make the estimates.

Estimates based on simulated data will depend heavily on the kind of irrigation rules assumed to represent farmers' behavior. In this report we have attempted to use irrigation rules as close as possible to farmers' actual behavior in Skåne.

Table 6. Average Water Supplied by Precipitation + Irrigation during each Two-Week Period (in mm)

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	Sept. 1-15	Sept. 16-31
Average Precipitation	20	22	21	32	30	41	34	39	30	26
Average of precipitation + irrigation:										
Potatoes				60	55	62	46	50		
Grain (sandy soil)			58	57	56					
Grain (clay soil)			60	56	56					
Vegetable oil		65	53	57	57					
Sugar beets					58	61	48	49	44	
Ley (harvested)		65	53	57	57	61	47			
Ley (grazing)		65	53	57	57	61	47	50	43	

The irrigation schemes are rules of thumb recommended to farmers, and depend only on daily measurement of rainfall. A major finding of the report is that use of these thumb rules leads to higher water use than does the use of more sensitive rules based on soil moisture. It would be worthwhile, in terms of water saved, to encourage farmers to measure soil moisture and to use more sophisticated irrigation schemes, rather than the rough thumb rules.

The report also presents a clear picture of the changes caused in the amount of water available to the crops by the assumed irrigation practices. Benefits include greatly increased seasonal water totals, and a consistent supply of water throughout the season. The schemes succeed quite well at providing 52-66 mm of water in each two-week period. The variability of total water supply is also greatly reduced by irrigation--an important benefit to farmers in terms of reducing risk, and one which is often overlooked. On the other hand, the simulation irrigation practices provide an excess of water, on average, compared to optimal monthly totals. This also suggests the value of adopting irrigation practices which match crop water needs more sensitively.

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