SPRINKLER IRRIGATION OF CLAY SOILS IN SOUTHERN FINLAND

IV. The effect of repeated applications of water and nitrogen fertilization on spring cereals

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Abstract. In 1967 and 1968, in the month of June, irrigation of silty clay soil in southern Finland by a single sprinkling, which involved the application of 30 mm of water, increased the yields of spring wheat by an average of between 880 and 970 kg per ha, or 37—51 %, and the yields of barley by 1140—1340 kg per ha, or 37—42 %. Repeating the irrigation after about one week further increased the wheat yields on the average by from 670 to 800 kg per ha and the barley yields between 810 and 860 kg per ha.

The effect of the irrigation on the size of the yields was virtually of the same magnitude both years in spite of the fact that in 1967 both June and July were extremely dry months, whereas in 1968 the dry June was followed by a rainy July. The sprinkling affected the ripening of the grain, on the other hand, differently each year: slightly retarding the ripening in 1967 but considerably hastening it in 1968. In the latter year, the irrigation prevented detrimental late tillering and thereby augmented the hectoliter weight and 1000-grain weight of the crops.

In response to the one-time sprinkling, the protein content of the grains decreased — in the case of the wheat by an average of 1.0—1.3 and of the barley by 0.1—0.7 %-units. The effect of two sprinklings was corresponding decreases of 1.9—3.1 and 0.8—1.0 %-units. The application to the seedlings as surface dressing immediately before irrigation of calcium nitrate containing 60 kg/ha of nitrogen increased the protein content of the wheat on the average by 1.6 and of the barley by 1.9 %-units. The nitrogen fertilization thus prevented excessive lowering of the protein content by irrigation and, furthermore, considerably intensified the salutary effect of the irrigation in augmenting the yield. A disadvantage of abundant nitrogen fertilization was a slight retardation of ripening.

The placement of basal dressing with a fertilizer drill at a depth of 9 cm proved effective, particularly in 1967, when both the wheat and the barley yields increased 22 per cent in comparison with the effect of surface dressing. Use of the fertilizer drill, moreover, promoted the ripening process. Sprinkling did not appear to reduce the placement effect of the fertilizer; rather did these two methods form an exceedingly favorable combination.

In 1964 a series of investigations was started with the aim of thoroughly ascertaining the effects of sprinkler irrigation on clay soils in southern Finland. In the years 1964—

66, a single sprinkling of 30 mm of water at the right time increased the yields of spring cereals between 25 and 50 per cent (Elonen, Nieminen and Kara 1967). The investigators observed that the effect of the sprinkling on the soil moisture conditions was of relatively short duration; it was therefore reasoned that more frequent sprinklings would probably have produced even better results. It was likewise surmised that the efficacy of the irrigation could have been increased by more abundant application of nitrogen fertilizer, which would at the same time have prevented the excessive reduction of the protein content of the grains caused by the irrigation. The validity of these assumptions was investigated in the following two-year period, 1967—68. The results arrived at are set forth in this publication.

Field experiments

Treatments and their symbols. The field experiments were laid out in a split-plot design (Steel and Torrie 1960), and they included four factors: as whole plots, four levels of irrigation (I); as subplots, two different crops; as sub-subplots, two levels of nitrogen fertilization (N); and as subsub-subplots, two fertilization depths (D). There were four replications; accordingly, the trials embraced 128 experimental plots. The experimental design was in principle similar to the one described in detail and illustrated by a diagram in a previous publication. (Elonen, Nieminen and Kara 1967).

The irrigation was performed at night by rotary sprinklers with a radius of 12 $\pm$ 2 m. Drainage ditch water with a pH of about 7 and electrical conductivity of < 0.1 mmho per cm was applied at a rate of 5 mm an hour, the total single application amounting to 30 mm. It was endeavored to perform the irrigation at a time when, in the light of previous experience, plants were most likely to benefit from it (Fig. 1). The irrigation dates were as follows:

1967	1968
I_0 = without irrigation	I_0 = without irrigation
I_1 = June 15	I_1 = June 9
I_2 = June 21	I_2 = June 9 and June 17
I_3 = June 15 and June 21	I_3 = June 9, 17 and 24

The experimental plants were spring wheat (Svenno variety) and barley (Ingrid variety). The crops were cultivated in the same way under identical growing conditions side by side.

The basal dressing (N_1) was applied in conjunction with the sowing May 12, 1967 and May 10, 1968. In the former year, 60 kg of N, 43 kg of P and 56 kg of K per hectare were applied in the form of compound fertilizer. In the latter year, the corresponding figures were 75, 44 and 62. The fertilization was carried out with a fertilizer drill, the coulters being spaced 16 cm apart; on the one hand, a placement depth of 9 cm was used (D_1), and on the other, the application was on the surface (D_0) with the plastic fertilizer tubes outdrawn from the coulters.

The application of the additional nitrogen (N_2) was performed with the same machine on the surface to the sprouts immediately before the initial irrigation. Nitrogen was applied as calcium nitrate in the amount of 60 kg N per ha; thus the nitrogen levels N_1 and N_2 in 1967 were 60 and 120 kg N per ha, and in 1968, 75 and 135 kg N per ha.

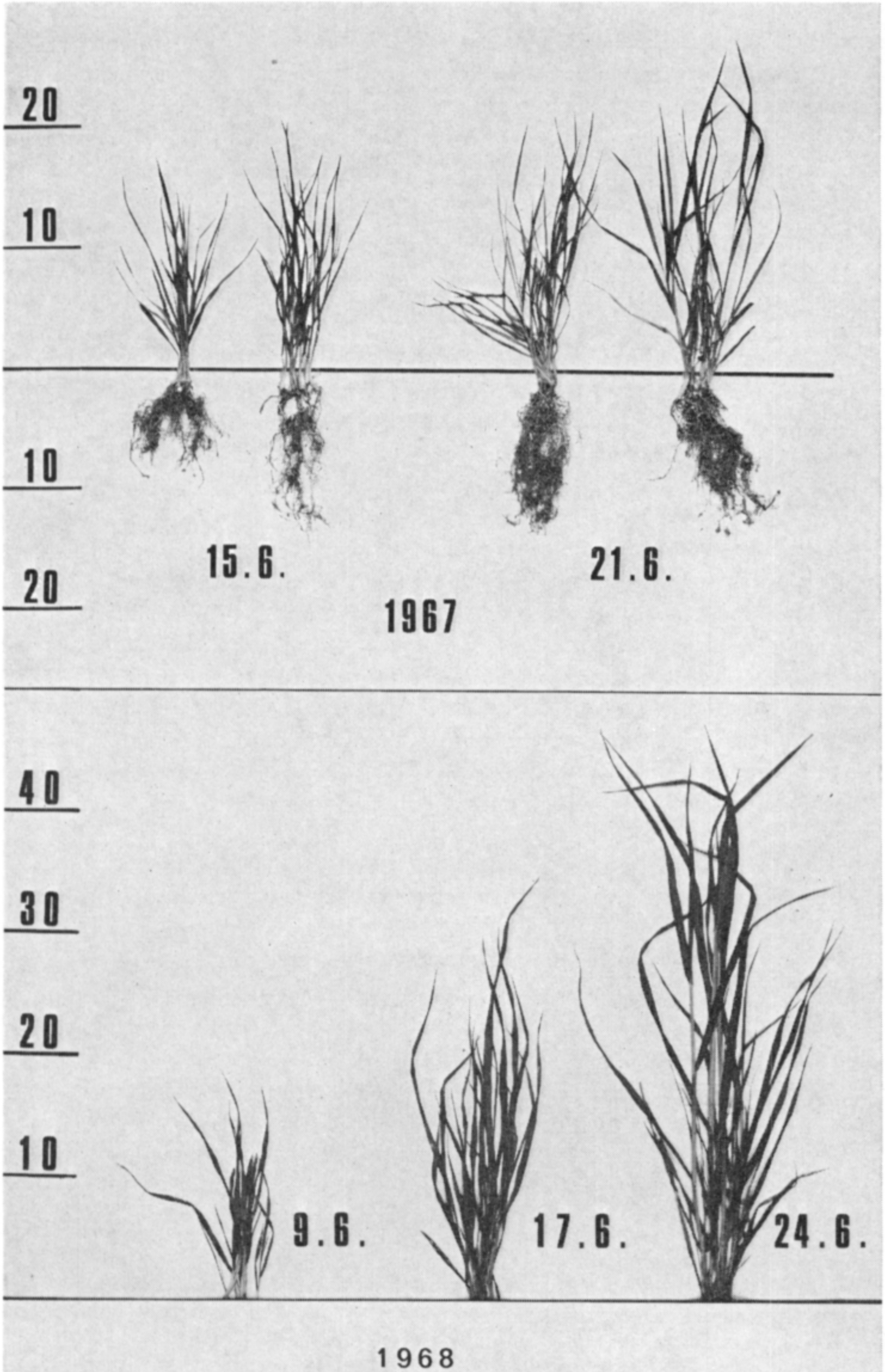

Fig. 1. The stages of development of barley on the dates of irrigation in 1967 (upper, fertilizer broadcast or placed) and 1968 (lower, fertilizer placed).

Experimental soils and their moisture conditions. The experimental plots were located in fields of silty clay on the farm maintained by the Research Foundation for Agricultural Machinery near Helsinki. The experimental soils were very much alike both years. The top soil contained an average of 50—52 per cent of the clay fraction (< 2 µm) and 3.4—4.0 per cent of organic carbon. The pH of the soils (in 0.01 M $CaCl_2$) varied between 5.4 and 6.1, and their nutrient condition was fairly good. The subsoils were heavy clays (clay content > 60 per cent).

The moisture condition of the soil was investigated by Bouyoucos' (1954) gypsum block method. Immediately after the sowing, 48 blocks were dug to three depths in 16 barley plots. The results of the measurements are given in Table 1 as averages for five-day periods.

As is well known, the method has certain drawbacks, so the results could scarcely correspond to the actual amounts of available water in the ground. The readings probably do, however, reflect fairly accurately the changes in the moisture condition of the soil and the effect of irrigation on them.

In 1967 both June and July were exceptionally dry months. The amount of »available water for plants» was reduced close to zero to a depth of 10 cm as of June 21, to a depth of 20 cm about a week later and to a depth of 40 cm some three weeks later. After that, there were no measurable amounts of available water for plants until August, when fairly heavy rainfalls moistened the surface layer of the ground.

The effect of a single 30-mm sprinkler irrigation was of rather short duration — only about one week. By June 21 the ground had dried out to such an extent that 30 mm of water could not suffice to moisten the soil to a depth of 20 cm. Watering of the surface did appear, however, to retard the drying of the soil at a depth of 40 cm. The moisture condition in twice-irrigated soil was evidently fairly beneficial to plant growth throughout the month of June, but by the beginning of July the top soil dried nearly to the wilting point.

In 1968 June was once more dry, and the top soil dried close to the wilting point. At the end of June and the beginning of July, the total precipitation was 70 mm during a three-week period; thanks to the generous rainfall, the ground was fairly moist throughout the month of July. The crops evidently utilized the first two irrigations rather completely, but after the third watering, performed on June 24, dry weather continued for only two days longer. The thrice-watered experimental plots were moister than the other plots for the rest of the summer.

The growth of the plants. In 1967 the grain crops emerged evenly. The beneficial effect of the placement of fertilizer could be perceived clearly after as short a time as two weeks after the emergence of the seedlings. Even more conspicuous was the effect of sprinkler irrigation. The watered crops were distinctly higher and denser than the unwatered ones. The barley was gathered with a combine harvester on August 24 and the wheat on August 30.

The rains that came right after the sowing in 1968 destroyed the porous structure of the soil surface and weakened the sprouting of the crops. The rains that followed in the wake of the dry month of June caused harmful late tillering of the unirrigated crops, which did not have time to ripen. The irrigated crops, by contrast, ripened evenly. The crops were harvested on September 5.

Table 1. "Available soil moisture" (%) at various depths in the barley plots. Mean values during the periods of five days.

Year Depth Irri- gation	mm	June 1—5	6—10	11—15	16—20	21—25	26—30	July 1—5	6—10	11—15	16—20	21—25	26—31	August 1—5	6—10	11—15	16—20	21—25	26—31
1967 10 cm																			
I_0	0	74	45	30	10	1	0	0	0	0	0	0	0	27	76	68	71	86	
I_1	30	56	39	22	75	3	0	0	0	0	0	0	0	4	11	12	20	33	
I_2	30	61	43	18	2	84	17	1	0	0	0	0	0	27	71	54	66	97	
I_3	60	68	39	25	68	81	34	3	0	0	0	0	0	8	28	28	45	63	
20 cm																			
I_0	0	83	74	56	33	6	1	0	0	0	0	0	0	2	7	7	12	18	
I_1	30	63	56	40	79	13	2	0	0	0	0	0	0	0	0	0	0	0	
I_2	30	66	49	33	13	19	8	1	0	0	0	0	0	0	0	0	2	3	
I_3	60	79	63	53	73	58	33	7	1	0	0	0	0	0	0	0	0	0	
40 cm																			
I_0	0	100	100	100	96	81	46	13	1	0	0	0	0	0	0	0	0	0	
I_1	30	90	80	73	76	70	60	38	8	1	0	0	0	0	0	0	0	0	
I_2	30	100	100	100	100	98	84	53	22	5	1	0	0	0	0	0	0	0	
I_3	60	100	100	100	100	100	95	66	19	2	0	0	0	0	0	0	0	0	
1968 10 cm																			
I_0	0	64	40	16	2	0	86	80	91	99	83	52	19	0	0	15	93	94	96
I_1	30	73	74	93	11	0	86	100	99	99	81	73	35	0	0	15	93	96	99
I_2	60	78	74	89	75	48	86	89	96	97	77	53	23	0	0	15	90	94	96
I_3	90	70	48	61	75	42	98	93	95	97	96	76	55	23	10	15	80	71	70
20 cm																			
I_0	0	97	72	43	13	2	16	49	74	97	92	63	29	0	0	2	14	40	66
I_1	30	99	88	99	19	2	70	97	97	98	95	67	26	0	0	10	59	70	83
I_2	60	100	87	99	72	45	86	98	98	96	94	64	32	0	0	4	25	55	79
I_3	90	98	87	85	72	42	100	100	99	98	95	82	55	10	4	15	78	90	99
40 cm																			
I_0	0	100	100	100	100	98	63	55	78	100	100	85	55	26	12	0	0	5	25
I_1	30	100	100	100	100	100	88	83	91	99	96	94	80	42	19	0	0	3	15
I_2	60	100	100	100	100	100	91	88	90	93	100	95	73	22	9	0	0	4	14
I_3	90	100	100	100	100	97	99	100	100	100	100	99	91	60	31	8	7	11	34
Precipitation mm																			
1967		4	3	2	0	5	0	7	1	0	0	12	4	0	31	10	9	43	18
1968		0	4	0	0	8	27	0	23	20	3	7	0	0	5	16	31	12	18

Results

Grain yields (Table 2). The sprinkler irrigation on June 15, 1967, increased the wheat yields an average of 970 (1900—2870) ± 430 kg per ha, or 51 ± 23 %, and

Table 2. Grain yields kg/ha, moisture 15 %.

Year plant	Irrigation	mm	N_1 D_0	N_1 D_1	N_1 mean	N_2 D_0	N_2 D_1	N_2 mean
1967	I_0	0	1590	2100	1840	1730	2170	1950
wheat	I_1	30	2320	2890	2600	2940	3330	3140
	I_2	30	2170	2850	2510	2830	3430	3130
	I_3	60	2860	3420	3140	3680	4200	3940
1967	I_0	0	2250	3110	2680	2480	3480	2980
barley	I_1	30	3170	3940	3550	4230	4760	4490
	I_2	30	3130	4040	3590	4090	4630	4360
	I_3	60	3840	4630	4230	5090	5800	5440
1968	I_0	0	2170	2280	2220	2640	2380	2510
wheat	I_1	30	3040	3160	3100	3440	3350	3400
	I_2	60	3760	3870	3810	4210	4340	4280
	I_3	90	3900	4130	4020	4630	4610	4620
1968	I_0	0	3570	3550	3560	3540	3890	3720
barley	I_1	30	4730	5020	4870	5020	5170	5100
	I_2	60	5610	5860	5730	5800	6080	5940
	I_3	90	5280	5540	5410	6030	6740	6380

Means, least significant differences (LSD), and significant interactions (*)

	1967, wheat	1967, barley	1968, wheat	1968, barley
I_0	1900	2830	2370	3640
I_1	2870	4030	3250	4980
I_2	2820	3970	4050	5840
I_3	3540	4840	4320	5900
LSD	430	680	410	580
N_1	2520	3510	3290	4890
N_2	3040	4320	3700	5280
LSD	140	310	150	380
D_0	2510	3530	3470	4950
D_1	3050	4300	3520	5230
LSD	80	160	110	150
	$I \times N$*			

the barley yields 1200 (2830—4030) ± 680 kg per ha, or 42 ± 24 %. The effect of the sprinkling carried out six days later was approximately of the same magnitude: the wheat crop increased 920 kg per ha, or 48 %, and the barley crop 1140 kg per ha, or 40 %. Two applications of water caused the wheat yields to increase by no less than 1640 kg per ha, or 86 %, and the barley yields by 2010 kg per ha, or 71 %. Repetition of the sprinkler irrigation (I_3—I_1) thereby augmented the wheat crops by an average of 670 kg per ha, or 35 %, and the barley crops by 810 kg per ha, or 29 %.

The effect of the watering was noticeably greater in the N_2 than N_1 plots. A single watering of the N_1 plots caused the wheat yields to increase by an average of 720 kg per ha, or 39 %, and the barley yields by 890 kg per ha, or 33 %, whereas the corresponding figures for the N_2 plots were 1190 kg per ha, or 61 %, and 1450 kg per ha, or 49 %. Correspondingly, two irrigation rounds in the N_1 plots augmented the wheat yields by an average of 1300 kg per ha, or 71 %, and the barley yields by 1550 kg per ha, or 58 %; but in the N_2 plots, the wheat yield increased as much as 1990 kg per ha, or 102 %, and the barley yield 2460 kg per ha, or 83 %.

Calcium nitrate applied to the shoots increased the average wheat yield by 520 ± 140 kg per ha, or 21 ± 6 %, and the barley yields by 810 ± 310 kg per ha, or 23 ± 9 %. The effect of additional nitrogen depended significantly on the sprinkler irrigation. Without irrigation, the additional application of nitrogen increased the wheat yields by only 110 kg per ha and the barley yields by 300 kg per ha. The corresponding figures for once-watered plots were 580 and 860 kg per ha and for twice-watered plots 800 and 1210 kg per ha. Sprinkler irrigation thus enhanced the efficacy of nitrogen fertilization many times over.

The placement of basal fertilizer to a depth of 9 cm augmented the wheat yields by an average of 540 ± 80 kg per ha, or 22 ± 3 %, and the barley yields by 770 ± 160 kg per ha, or 22 ± 5 %. The placement effect of fertilizer on the wheat yields was an increase of 470 kg per ha without irrigation, 560 kg per ha with a single watering and 540 kg per ha with two waterings. The corresponding figures for barley were 930, 690 and 750 kg per ha. Sprinkler irrigation did not therefore significantly decrease the placement effect of the fertilizer. The placement of basal fertilizer augmented the wheat yields of the N_1 plots by 580 kg per ha and of the N_2 plots by 490 kg per ha. The corresponding figures for barley were 830 and 700 kg per ha. The application of additional nitrogen to young crops thus tended to decrease the placement effect of the basal dressing, but the interaction was not statistically significant.

In 1968 a single sprinkling augmented the wheat yields by an average of 880 ± 410 kg per ha, or 37 ± 17 %, and the barley yields by 1340 ± 580 kg per ha, or 37 ± 16 %. Two waterings augmented the wheat yields, in comparison with unirrigated crops, by 1680 ± 410 kg per ha, or 71 ± 17 %, and the barley yields by 2200 ± 580 kg per ha, or 60 ± 16 %. Repetition of the sprinkler irrigation (I_2—I_1) thereby augmented the wheat yields by 800 ± 410 kg per ha, or 25 ± 13 %, and the barley yields by 860 ± 580 kg per ha, or 17 ± 12 %. A third sprinkling tended to increase the yields further, but the effect was no longer statistically significant.

The effect of dressing with additional nitrogen was noticeably slighter than the year before: the wheat crop increased an average of 410 ± 150 kg per ha, or 12 ± 5 %, and the barley crop 390 ± 380 kg per ha, or 8 ± 8 %. The positive interaction between nitrogen dressing and sprinkler irrigation was likewise noticeable only to a very slight degree: nitrogen dressing increased the wheat yields of plots I_0, I_1, I_2 and I_3 by 290, 300, 470 and 600 kg per ha and the barley yields, correspondingly, by 160, 230, 210 and 970 kg per ha.

The significance of the placement of the basal dressing was likewise substantially slighter than in the previous year and statistically significant only in the case of the barley plots, where the yields increased on the average by 280 ± 150 kg per ha, or 6 ± 3 %. As in the previous year, sprinkler irrigation and additional nitrogen applied to the seedlings did not appear to have decreased the placement effect of the basal dressing.

Table 3. Moisture of grains at the harvest, %.

Year plant	Irrigation	mm	N_1 D_0	N_1 D_1	N_1 mean	N_2 D_0	N_2 D_1	N_2 mean
1967	I_0	0	27.5	25.4	26.4	28.0	26.0	27.0
wheat	I_1	30	26.4	25.0	25.7	26.2	25.9	26.0
	I_2	30	26.5	25.2	25.8	27.8	27.0	27.4
	I_3	60	28.1	26.6	27.3	29.2	28.3	28.7
1967	I_0	0	26.2	25.1	25.7	27.8	25.2	26.5
barley	I_1	30	26.8	25.4	26.1	28.7	25.6	27.2
	I_2	30	28.6	26.7	27.7	31.0	28.0	29.5
	I_3	60	27.9	26.6	27.3	31.0	27.8	29.4
1968	I_0	0	30.5	27.9	29.2	32.3	32.1	32.2
wheat	I_1	30	23.3	23.6	23.5	26.5	27.9	27.2
	I_2	60	20.6	21.9	21.2	24.1	25.1	24.6
	I_3	90	21.1	21.7	21.4	23.3	23.6	23.5
1968	I_0	0	35.1	35.7	35.4	39.2	37.9	38.5
barley	I_1	30	25.3	24.9	25.1	27.4	28.0	27.7
	I_2	60	20.2	20.5	20.4	22.7	23.5	23.1
	I_3	90	20.4	19.9	20.2	21.6	20.6	21.1

Means, least significant differences (LSD), and significant interactions (*)

	1967, wheat	1967, barley	1968, wheat	1968, barley
I_0	26.7	26.1	30.7	37.0
I_1	25.9	26.6	25.3	26.4
I_2	26.6	28.6	22.9	21.7
I_3	28.1	28.3	22.4	20.6
LSD	1.5	0.9	3.3	5.5
N_1	26.3	26.7	23.8	25.3
N_2	27.3	28.1	26.9	27.6
LSD	0.5	0.3	0.8	0.8
D_0	27.4	28.5	25.2	26.5
D_1	26.2	26.3	25.5	26.4
LSD	0.4	0.3	0.5	0.5
		I × N* N × D***	I × D**	

M o i s t u r e o f g r a i n s a t h a r v e s t (Table 3). In 1967 the irrigation significantly affected the ripening of the cereal crops only in the barley plots. The moisture of the grains at threshing time was 2.5 ± 0.9 %-units higher in the twice-irrigated than in the unirrigated plots. The additional nitrogen also slightly retarded the ripening, increasing the moisture content of the wheat by 1.0 ± 0.5 and that of the barley by 1.4 ± 0.3 %-units. Placement of the basal dressing, on the other hand, had the effect of promoting the ripening process: the moisture content of the wheat was 1.2 ± 0.4 and that of the barley grains 2.2 ± 0.3 %-units lower in the experimental plots treated with placed fertilizer than in the plots treated with surface dressing.

Table 4. Protein contents of grains, % of DM.

Year plant	Irrigation	mm	N_1 D_0	N_1 D_1	N_1 mean	N_2 D_0	N_2 D_1	N_2 mean
1967	I_0	0	14.4	14.5	14.4	16.5	16.1	16.3
wheat	I_1	30	13.2	13.4	13.3	15.1	15.7	15.4
	I_2	30	13.4	13.3	13.3	15.3	15.5	15.4
	I_3	60	12.5	12.4	12.4	14.3	15.0	14.7
1967	I_0	0	11.9	12.1	12.0	13.9	13.8	13.8
barley	I_1	30	11.8	11.7	11.8	13.9	13.8	13.9
	I_2	30	11.9	11.5	11.7	13.9	13.8	13.8
	I_3	60	11.0	11.2	11.1	13.2	13.1	13.2
1968	I_0	0	16.1	16.6	16.4	17.9	18.3	18.1
wheat	I_1	30	15.1	15.4	15.3	16.2	16.9	16.6
	I_2	60	13.8	13.2	13.5	14.8	14.8	14.8
	I_3	90	12.9	13.3	13.1	14.3	14.5	14.4
1968	I_0	0	14.2	14.4	14.3	15.6	15.5	15.6
barley	I_1	30	13.5	12.9	13.2	15.1	15.2	15.2
	I_2	60	13.1	12.9	13.0	14.7	14.9	14.8
	I_3	90	11.9	11.9	11.9	13.7	13.9	13.8

Means, and least significant differences (LSD). No significant interactions.

	1967, wheat	1967, barley	1968, wheat	1968, barley
I_0	15.4	12.9	17.2	14.9
I_1	14.4	12.8	15.9	14.2
I_2	14.4	12.8	14.1	13.9
I_3	13.5	12.1	13.8	12.8
LSD	0.7	0.5	1.9	1.2
N_1	13.4	11.6	14.6	13.1
N_2	15.4	13.7	16.0	14.8
LSD	0.3	0.2	0.4	0.4
D_0	14.4	12.7	15.2	14.0
D_1	14.5	12.6	15.4	14.0
LSD	0.2	0.2	0.3	0.3

In 1968 the differences in the moisture content of the cereal crops were very great, owing to late tillering, and the sprinkler irrigation had an exceedingly beneficial effect on the ripening of the grain: once sprinkled, the wheat was 5.4 ± 3.3 %-units, and twice sprinkled, 8.3 ± 3.3 %-units drier than unirrigated wheat. With respect to the barley, the corresponding differences were even greater — 10.6 ± 5.5 and 15.3 ± 5.5 %-units. Differences in moisture content of such magnitude were partly due to the fact that the unirrigated barley crop included 4.8 %, the once-watered crop 3.0 % and the twice-watered crop only 0.8 % of green grains. Even a third application of water seemed to promote further the ripening of the crops. As in the previous year, the application of

Table 5. 1000-grain weights, g.

Year plant	Irrigation	mm	N_1 D_0	N_1 D_1	N_1 mean	N_2 D_0	N_2 D_1	N_2 mean
1967	I_0	0	33.2	33.1	33.1	32.9	32.9	32.9
wheat	I_1	30	33.5	34.1	33.8	33.2	34.1	33.6
	I_2	30	32.9	33.6	33.2	33.2	34.5	33.9
	I_3	60	33.4	34.2	33.8	34.1	35.5	34.8
1967	I_0	0	45.7	45.6	45.7	46.1	45.8	46.0
barley	I_1	30	45.8	45.7	45.8	46.3	45.6	46.0
	I_2	30	46.0	46.0	46.0	45.8	45.6	45.7
	I_3	60	46.4	46.6	46.5	46.5	46.1	46.3
1968	I_0	0	34.3	36.4	35.3	35.7	36.1	35.9
wheat	I_1	30	37.9	37.9	37.9	38.2	38.7	38.4
	I_2	60	37.2	37.9	37.5	38.2	38.0	38.1
	I_3	90	36.2	36.5	36.4	37.6	37.9	37.8
1968	I_0	0	49.3	50.0	49.7	48.8	50.0	49.4
barley	I_1	30	51.9	52.0	52.0	52.0	51.9	52.0
	I_2	60	51.4	52.1	51.7	52.2	52.6	52.4
	I_3	90	51.2	51.2	51.2	50.9	51.5	51.2

Means, least significant differences (LSD), and significant interactions (*)

	1967, wheat	1967, barley	1968, wheat	1968, barley
I_0	33.0	45.8	35.6	49.5
I_1	33.7	45.9	38.2	52.0
I_2	33.5	45.8	37.8	52.1
I_3	34.3	46.4	37.1	51.2
LSD	0.9	0.9	1.4	2.4
N_1	33.5	46.0	36.8	51.1
N_2	33.8	46.0	37.6	51.2
LSD	0.3	0.4	0.3	0.5
D_0	33.3	46.1	36.9	51.0
D_1	34.0	45.9	37.4	51.4
LSD	0.3	0.3	0.4	0.5
	I × N** I × D*	N × D*		

additional nitrogen retarded the ripening of the cereal crops: the moisture difference in the case of the wheat was 3.1 ± 0.8 and that in the case of the barley 2.3 ± 0.8 %-units. The placement of basal dressing, on the other hand, had no effect on the ripening process.

Protein content of grains (Table 4). In 1967 a single sprinkling reduced the protein content of wheat (5.7 × total N) on an average by 1.0 ± 0.7 and two sprinklings by 1.9 ± 0.7 %-units. The protein content of barley (6.25 × total N) was reduced by a single sprinkling by 0.1 ± 0.5 and two sprinklings by 0.8 ± 0.5 %-units. Sprinkler irrigation carried out once did not therefore significantly cause a decrease in the protein content of barley. Additional nitrogen applied to young crops markedly increased the

Table 6. Hectoliter weights, kg.

Year plant	Irrigation	mm	N_1 D_0	N_1 D_1	N_1 mean	N_2 D_0	N_2 D_1	N_2 mean
1967	I_0	0	79.9	79.3	79.6	78.5	78.8	78.6
wheat	I_1	30	80.0	79.7	79.8	78.1	79.0	78.5
	I_2	30	79.4	79.0	79.2	78.0	79.1	78.6
	I_3	60	79.0	79.0	79.0	77.4	78.8	78.1
1967	I_0	0	73.4	73.8	73.6	72.6	72.4	72.5
barley	I_1	30	73.5	72.5	73.0	72.4	72.8	72.6
	I_2	30	72.6	72.8	72.7	71.8	73.1	72.4
	I_3	60	71.9	72.4	72.1	72.3	71.3	71.8
1968	I_0	0	79.7	80.4	80.1	79.1	79.1	79.1
wheat	I_1	30	80.9	81.0	81.0	80.6	80.0	80.3
	I_2	60	81.2	81.1	81.1	80.7	80.4	80.6
	I_3	90	80.8	80.8	80.8	80.6	80.4	80.5
1968	I_0	0	69.7	68.9	69.3	67.5	68.6	68.1
barley	I_1	30	70.6	70.8	70.7	70.4	70.7	70.5
	I_2	60	71.5	71.5	71.5	71.5	71.5	71.5
	I_3	90	71.5	71.6	71.6	71.7	72.7	72.2

Means, least significant differences (LSD), and significant interactions (*)

	1967, wheat	1967, barley	1968, wheat	1968, barley
I_0	79.1	73.1	79.6	68.7
I_1	79.2	72.8	80.6	70.6
I_2	78.9	72.5	80.9	71.5
I_3	78.5	71.9	80.7	71.9
LSD	0.9	0.6	0.8	1.1
N_1	79.4	72.8	80.7	70.8
N_2	78.4	72.3	80.1	70.6
LSD	0.4	0.3	0.2	0.6
D_0	78.8	72.6	80.5	70.5
D_1	79.0	72.6	80.4	70.8
LSD	0.2	0.3	0.2	0.4
	N × D***		I × N* N × D**	

protein content: that of wheat by 2.0 ± 0.3 and that of barley by 2.1 ± 0.2 %-units. The placement of basal dressing had no effect on the protein content.

In 1968 a single sprinkling reduced the protein content of wheat on an average by 1.3 ± 1.9, two sprinklings by 3.1 ± 1.9, and three sprinklings by 3.4 ± 1.9 %-units. On the part of the barley, the corresponding differences were 0.7 ± 1.2, 1.0 ± 1.2 and 2.1 ± 1.2. Additional nitrogen dressing raised the protein content of the wheat by 1.4 ± 0.4 and that of the barley by 1.7 ± 0.4 %-units. As in the previous year, the placement of basal dressing had no effect on the protein content of the grains.

W e i g h t o f t h e g r a i n s (Table 5). In 1967 the effect of irrigation on the weight of the grains was slight and significant only in the case of the twice-watered wheat plots, in which the irrigation raised the weight of 1000 grains on an average by 1.3 ± 0.9 g. The effect of the irrigation was most marked in the case of those wheat plots in which basal dressing had been placed and which had received additional nitrogen. Both the placement of basal dressing and the application of additional nitrogen tended to increase the weight of the wheat grains; but they had no effect on the weight of the barley grains.

In 1968 a single sprinkling raised the weight of 1000 wheat grains on an average by 2.6 ± 1.4 and of 1000 barley grains by 2.5 ± 2.4 g. A second or third application of water no longer caused any increase in the weight of the grains but tended, on the contrary, to lower it. As in the year before, the placement of basal dressing and the application of additional nitrogen slightly increased the weight of the wheat grains but had no effect on the weight of the barley grains.

Hectoliter weights (Table 6). In 1967 sprinkler irrigation had no significant effect on the hectoliter weight of the wheat, but that of the barley was lowered as a result of two waterings on an average by 1.2 ± 0.6 kg. The application of additional nitrogen reduced the hectoliter weight of wheat on an average by 1.0 ± 0.4 and that of barley by 0.5 ± 0.3 kg. The placement of basal dressing had no significant effect.

In 1968 sprinkler irrigation distinctly improved the hectoliter weight of both the wheat and, in particular, the barley. The increases brought about by one, two and three sprinklings in the case of the wheat were 1.0 ± 0.8, 1.3 ± 0.8 and 1.1 ± 0.8 and, correspondingly, in the case of the barley, 1.9 ± 1.1, 2.8 ± 1.1 and 3.2 ± 1.1 kg. The application of additional nitrogen reduced the hectoliter weight of the wheat on an average by 0.6 ± 0.2 kg — but it had no significant effect on the barley. The placement of basal dressing had no significant effect.

Discussion

The experimental years constitute quite an interesting pair. Common to the two years was a dry June up to the month's 26th day. Even after that date, in 1967, the dry spell stretched out all the way to August, and the ground became parched. In 1968, however, there was fairly abundant rainfall at the end of June and the early part of July, with the effect that the ground was moist all through the middle of the summer.

In spite of the difference between the midsummer period of the two years, the effect of the sprinkler irrigation carried out in June on the size of the harvest was highly similar both years. A single sprinkling augmented the wheat yields on an average by 880—970 kg per ha, or 37—51 %, and the barley yields by 1140—1340 kg per ha, or 37—42 %. Two sprinklings increased the wheat yields on an average by 1640—1680 kg per ha, or 71—86 %, and the barley yields by 2010—2200 kg per ha, or 60—71 %. Repetition of the watering thus further augmented the yields quite markedly, although, to be sure, the increase brought about by the second sprinkling was in the case of the wheat on an average 1/4 smaller and in the case of the barley 1/3 smaller than the crop increase obtained through the first sprinkler irrigation.

The effect of the sprinkler irrigation on the protein contents of the crops was also very much the same both years. A single sprinkling lowered the protein contents of the wheat on an average by 1.0—1.3 and of the barley by 0.1—0.7 %-units. Two sprinklings reduced the protein contents correspondingly by 1.9—3.1 and 0.8—1.0 %-units. It therefore looks as if sprinkler irrigation reduces the protein content of wheat more drastically than that of barley.

In the drought year of 1967, the unirrigated cereal crops ripened, as if under pressure, earlier than normally; thus irrigation ostensibly delayed the ripening, though only very slightly. The following summer, the rainy midsummer season brought about detrimental late tillering of unirrigated crops and thereby delayed ripening. Under such conditions, the irrigation had the contrary effect, one of preventing belated tillering of the crops and promoting the ripening process.

The findings of the investigation prove conclusively that the weather conditions prevailing in the month of June have a decisive effect on the development of spring cereal crops in the areas of clayey soil in southern Finland. If the month of June is short on rain, crops are incapable of effectively utilizing the nutrients contained in the parched earth and growth of plant life is weak. If also the middle and late summer seasons are dry, unirrigated soil is liable to have left over an abundance of unutilized plant nutrients (Kaila and Elonen 1971). If a dry June is succeeded by a rainy July, the abundant nitrogen reserves and sparse growth stimulate belated tillering of plants — which to some extent improves the harvest but at the same time delays its ripening.

By sprinkler irrigation, the nutrient reserves in the ground can be made effectively available to plants as early as June (Kaila and Elonen 1970), a dense plant association develops and it ripens evenly regardless of the weather conditions prevailing during the middle and late summer seasons. It has been pointed out in previous studies that the most critical season for spring cereal crops is about three or four weeks long midway between the emergence of the plants and the appearance of the ears. The effect of irrigation at this time remains virtually unchanged provided the dry spell continues (Elonen, Nieminen and Kara 1967). The findings of the present investigation confirm, as far as they go, the results of earlier research: the irrigations carried out on June 15 and June 21, 1967, proved by and large equally beneficial.

Calcium nitrate containing 60 kg N/ha, when applied to the seedlings, increased the protein content of the wheat on an average by 1.6 and of the barley by 1.9 %-units. The excessive reduction of the protein content induced by irrigation could thereby be forestalled, besides which the effect of the watering on the size of the harvest improved noticeably. The amounts of nitrogen of the N_2-level, 120 and 135 kg N per ha, seem to be highly suitable to the fertilization of a wheat field awaiting irrigation. The amounts of fertilizer applied to the malting barley proved to be excessive, however, for in spite of the sprinkler irrigation the protein contents exceeded 12 per cent.

The placement of basal dressing to a depth of 9 cm improved its utilization by the crops quite effectively, especially in 1967. Once again, the same astonishing result was arrived at as in previously reported investigations: irrigation did not diminish the placement effect of fertilizer (Elonen, Nieminen and Kara 1967; Kaila and Elonen 1970). Plants grow around the rows with placed fertilizer thick root clusters, which thirstily suck the ground dry and the watering of which is probably particularly advantageous (Kähäri and Elonen 1969). After the irrigation, the ground dries up once more, first at the surface and only later at the placement depth; accordingly, irrigation is likely to improve for a longer time the utilization of placed nutrients than of those applied onto the surface. It is known, furthermore, that in clayey soil sprinkling does not to any noteworthy extent carry downward other macronutrients than nitrate (Aura 1967). This also emphasizes the importance of fertilization by placement.

Quite favorable results have been obtained with the placement of fertilizer in Finland (Larpes 1967, Nieminen, Kara and Elonen 1967, Kivi and Hovinen 1969, Pessi et al. 1970, Paulamäki and Luostarinen 1971). It seems clear that this method could be profitably applied also in irrigated fields. It is possible that also additional nitrogen, which in the present investigation was given to seedlings, could be advantageously applied in immediate conjunction with sowing by the placement technique.

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SELOSTUS

KEVÄTVILJOJEN SADETUKSESTA ETELÄ-SUOMEN SAVIMAILLA. IV. SADETUKSEN UUSIMISEN JA TYPPILANNOITUKSEN VAIKUTUS.

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Vuosina 1967 ja 1968 yksi kesäkuussa suoritettu 30 mm:n sadetus hiesusavimailla Espoossa lisäsi keskimäärin kevätvehnäsatoja 880—970 kg/ha eli 37—51 % ja ohrasatoja 1140—1340 kg/ha eli 37—42 %.

Sadetuksen uusiminen noin viikon kuluttua lisäsi edelleen vehnäsatoja keskimäärin 670—800 kg/ha ja ohrasatoja 810—860 kg/ha.

Sadetuksen vaikutus sadon määrään oli kumpanakin vuonna likimain samansuuruinen huolimatta siitä, että vuonna 1967 sekä kesäkuu että heinäkuu olivat erittäin kuivia mutta vuonna 1968 kuivaa kesäkuuta seurasi sateinen heinäkuu. Viljan tuleentumiseen sadetus sensijaan vaikutti eri vuosina eri tavalla: vuonna 1967 lievästi tuleentumista hidastaen mutta vuonna 1968 sitä suuresti edistäen. Jälkimmäisenä vuonna sadetus esti haitallisen myöhäisversonnan ja samalla lisäsi viljojen hehtolitran painoa ja 1000-jyvän painoa.

Jyvien valkuaispitoisuus aleni kertasadetuksen vaikutuksesta keskimäärin vehnällä 1.0—1.3 ja ohralla 0.1—0.7 %-yksikköä sekä kahden sadetuksen vaikutuksesta vastaavasti 1.9—3.1 ja 0.8—1.0 %-yksikköä. Oraille välittömästi ennen ensimmäistä sadetusta pintalannoituksena annettu kalkkisalpietari, joka sisälsi typpeä 60 kg/ha, kohotti valkuaispitoisuutta vehnällä keskimäärin 1.6 ja ohralla 1.9 %-yksikköä. Typpilannoitus esti siten sadetuksen aiheuttaman valkuaispitoisuuden liiallisen alenemisen ja samalla tehosti huomattavasti sadetuksen satoa lisäävää vaikutusta. Runsaan typpilannoituksen epäkohtana oli lievä tuleentumisen viivästyminen.

Aluslannoituksen sijoittaminen rivilannoittimella 9 cm:n syvyyteen vaikutti tehokkaasti erityisesti vuonna 1967, jolloin sekä vehnä- että ohrasato lisääntyivät 22 % pintalannoitukseen verrattuna. Lisäksi rivilannoitus edisti tuleentumista. Sadetus ei näyttänyt vähentävän lannoitteen sijoitusvaikutusta, vaan nämä kaksi menetelmää muodostivat erittäin edullisen yhdistelmän.