SPRINKLER IRRIGATION ON CLAY SOILS IN SOUTHERN FINLAND

II. Effect on the grain yield of spring yereals

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In the dry growing seasons 1964, 1965 and 1966, irrigation experiments of spring cereals were carried out on clay soils in Southern Finland. The results of the investigations concerning the technique of sprinkler irrigation and the soil moisture conditions have been published in the first part (ELONEN, NIEMINEN and KARA 1967).

The present paper will report the results of sprinkler irrigation on the grain yield. Attention has been paid to the importance of the date of irrigation, the crop, the amount of fertilizers and the placement of fertilizers.

Experimental

Every year, the experimental design was similar to that in Figure 1, even if the factors were different in different years. As main plots were »sprinkling circles», which were arranged as a »Latin square» so that two similar treatments did not occur side by side. »Split plots» and »split split plots» were placed as impartially as possible into the sprinkling circles alternately nearer and farther from the sprinklers, so that the ununiform action of sprinklers would not get to the account of variously treated plots.

The gross and the net sizes of the experimental plots were 2×24 m^2 and 1.75×16 m^2, respectively. In the years 1964, 1965 and 1966 the number of replications was 4, 6 and 5 which means that in all there were 48, 144 and 150 experimental plots in the respective years.

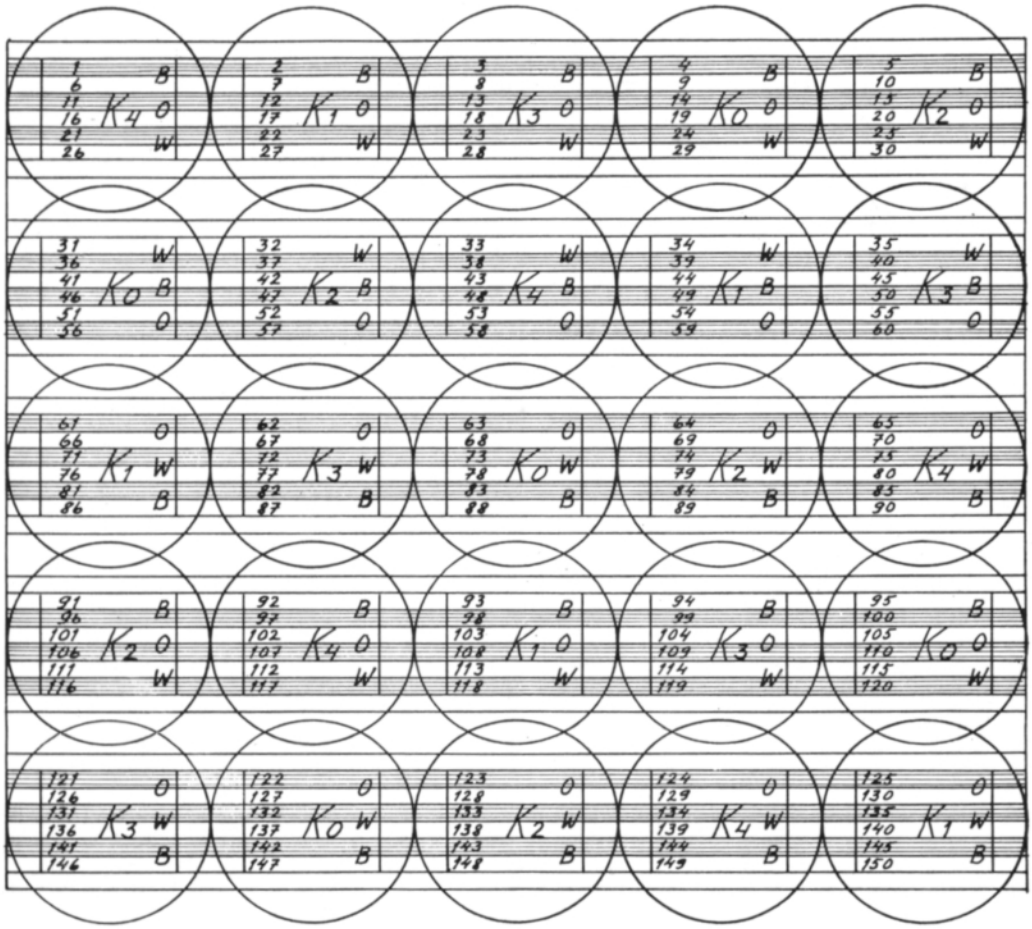


Figure 1. Irrigation experiment of spring cereals in 1966.

I. Date of irrigation
- K_0 = Not irrigated
- K_1 = On June 13th
- K_2 = On June 19th
- K_3 = On June 26th
- K_4 = On July 4th

II. Fertilizer
- = Broadcasted
- = Placed

III. Plant
- W = Wheat
- B = Barley
- O = Oats

Exp. field 100 × 120 m², Exp. plot 1.75 × 16 m², Radius of sprinklers 12 ± 2 m.

The cultivation procedures with the exception of irrigation and placement of fertilizers were normal. The irrigation technique has been reported in the previous paper (ELONEN, NIEMINEN and KARA 1967). The fertilizers were applied between seed-bed preparation and sowing. The placement of fertilizers was carried out with a Finnish »Juko» fertilizer drill, with which compound fertilizer 8—13—9 was placed in rows with a distance of 15 cm and to the depth of 8—12 cm. The same machine with the same adjustments was also used for the broadcasting of the fertilizers.The only difference was that the plastic fertilizer tubes were drawn out from the coulters,

Table 1. The effect of irrigation on grain yield.

Year	Irrigation		Yield, kg/ha (moisture 15 %)			Relative values		
Plant			Fertilizer			Fertilizer		
	date	amount (mm)	broad-casted	placed	Average	broad-casted	placed	Average
1964	—	—	2320	2390	2360	100	100	100
Wheat	30. 5.	15	2260	2470	2360	97	103	100
	23. 6.	35	2960	2920	2940	128	122	125
		L.S.D.	290	290	140	13	12	6
1965	—	—	1550	1940	1740	100	100	100
Wheat	18. 6.	37	2020	2700	2360	130	139	136
	2. 7.	37	1590	1970	1780	103	102	102
		L.S.D.	210	210	150	14	11	9
1966	—	—	1740	2460	2100	100	100	100
Wheat	13. 6.	30	3020	3350	3180	174	136	151
	19. 6.	30	2960	3370	3170	170	137	151
	26. 6.	30	2830	3360	3100	163	137	148
	4. 7.	35	2400	2990	2700	138	122	129
		L.S.D.	380	380	250	22	15	12
1966	—	—	2710	3380	3040	100	100	100
Barley	13. 6.	30	4140	4420	4280	153	131	141
	19. 6.	30	3860	4420	4140	142	131	136
	26. 6.	30	4370	4920	4650	161	146	153
	4. 7.	35	3450	4070	3760	127	120	124
		L.S.D.	740	740	480	27	22	16
1966	—	—	3140	3450	3300	100	100	100
Oats	13. 6.	30	4210	4520	4360	134	131	132
	19. 6.	30	4250	4560	4410	135	132	134
	26. 6.	30	4730	5010	4870	151	145	148
	4. 7.	35	4140	4770	4450	132	138	135
		L.S.D.	610	610	400	19	18	12

when the fertilizer was broadcasted on the surface of soil. Thus, the amount of fertilizer and the tillage effect were quite the same in both cases. It is noticed that the broadcasted fertilizers were to some extent covered with soil by the coulters of fertilizer drill and by those of sowing machine and by rolling, but not by harrowing.

In the experimental years 1964, 1965 and 1966, the average amounts of compound fertilizer 8—13—9 were 700, 750 and 870 kg/ha, respectively.

The harvest was carried out with a normal combine-harvester. The fresh yields of the experimental plots were directly weighed on the field. For the determinations of dry matter and other analyses, representative subsamples of 0,5—1 kg were taken into plastic bags.

Each year, the experimental plant was spring wheat (Svenno), in 1966 also barley (Ingrid) and oats (Hannes) were included.

Results

The date of irrigation. It can be seen from Table 1 that the date of irrigation and the placement of fertilizers have had a remarkable effect on the grain yields of spring cereals. First, attention is paid to the date of irrigation and thus to the mean values in Table 1. It must be noticed that the experimental plots were irrigated only once, different plots at different dates.

In 1964, at the stage of sprouting, 15 mm of water was applied, but it had, however, no effect on the yield. At the date of irrigation, deficiency of water appeared only in the surface layer of soil. Thus, the effect of irrigation was to assure a uniform sprouting. When the amount of sprouts, according to a determination carried out later, was found to be practically the same on the plots irrigated und unirrigated, or 58 and 56 per meter respectively, the ineffectiveness of early irrigation is easy to understand.

Three weeks later, the plants already suffered from a lack of water, and the irrigation of 35 mm applied at this time increased the grain yield of spring wheat by 580 kg/ha or 25 %.

In 1965, the sprinklings were again carried out at two dates. The first one was applied three weeks from sprouting, or about at the same stage of development as the latter one in 1964. The increase in yield was also of the same order: 630 kg/ha or 36 % with the irrigation of 37 mm.

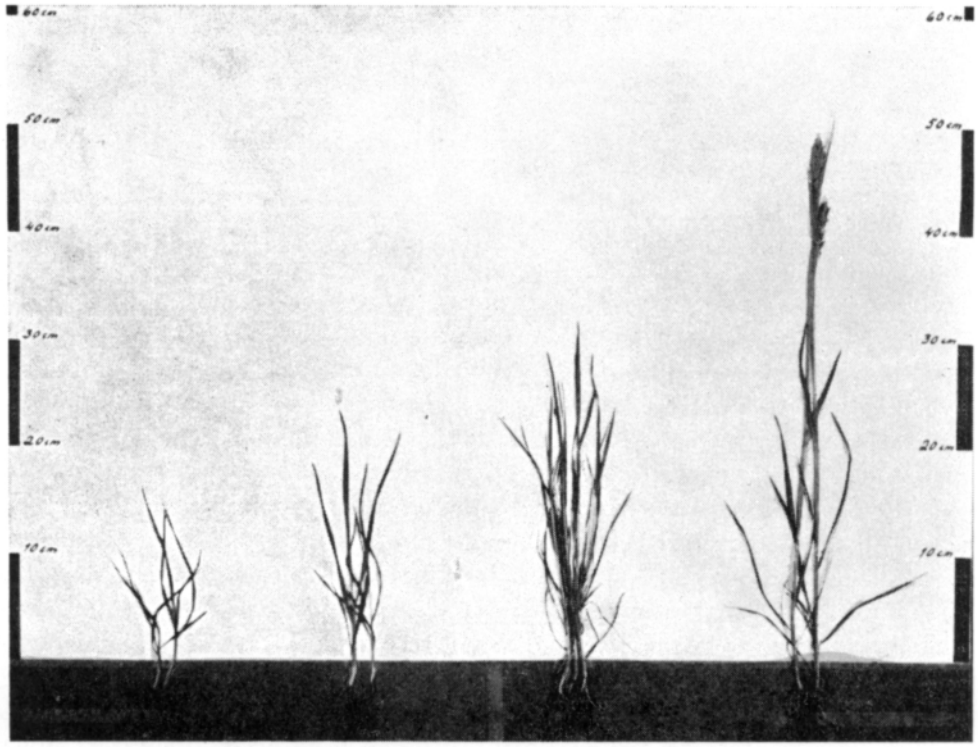
The irrigation of 37 mm applied two weeks later, failed, because then the dry period ended. The whole middle and latter part of the summer was very rainy, and the plants were likely to suffer more from a lack of air than from the lack of water. Accordingly, any increase in yield from irrigation could not be expected. It is noteworthy, however, that the yield was not lower than without irrigation.

On the basis of the results of these two years any far-reaching conclusions about the best irrigation date of spring cereals could not yet be drawn. Each year, the irrigation applied three weeks after sprouting had increased the grain yield of spring wheat with about 600 kg/ha. However, was this the best date for irrigation.

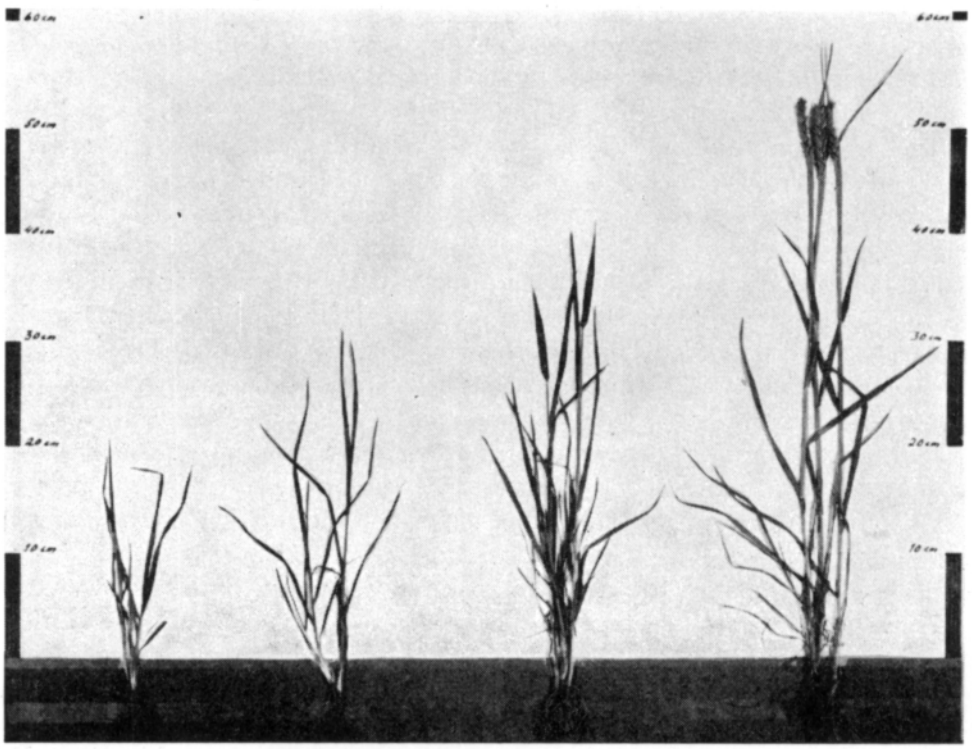
In 1966, the sprinklings were applied at the intervals of about one week. The first one was carried out as soon as the available water at the depth of 20 cm lowered to 50 % of the total capacity. This happened on the 13th of June or two and a half weeks after sprouting. At all the four dates applications of water, obviously, brought the full benefit for plants, because the dry period was unusually long and warm.

Figure 2 represents the stages of development of spring wheat at the different dates of irrigation in 1966. The rates of growth of barley and oats were almost similar to that of wheat. It should be noticed that the fourth irrigation was applied three days after ear emergence.

The first three sprinklings of 30 mm to wheat were almost equal in effect. Each one increased the yield by about 1050 kg/ha or 50 %. The effect of the fourth irriga-



K_1 June 13 K_2 June 19 K_3 June 26 K_4 July 4



K_1 June 13 K_2 June 19 K_3 June 26 K_4 July 4

Figure 2. The stages of development of spring wheat at the dates of irrigation in 1966. Broadcasting (upper) and placement to the depth of 9 cm (lower) of fertilizer.

tion of 35 mm, carried out three days after ear emergence, was lower. Yet, also then the increase in yield was 600 kg/ha or 29 %.

Barley responded to sprinklings in somewhat different way than did wheat: The first two applications of water increased the yield almost equally, in average by 1170 kg/ha or 39 %, but the third one, also 30 mm in amount, which was applied one week before ear emergence increased the yield significantly more, by 1610 kg/ha or 53 %. The effect of the latest irrigation was the lowest both on barley and on wheat. An increase in yield of 720 kg/ha or 24 % was obtained.

Oats gained by the three first sprinklings in a way corresponding to that of barley: The effect of the first two applications of water was in average +1090 kg/ha or +33 %, but that of the third significantly more, +1570 kg/ha or 48 %. The latest date of irrigation was to oats not the most unprofitable as it was to wheat and barley, but as profitable as the two first dates of irrigation: +1150 kg/ha or +35 %.

On the basis of the experiments carried out in 1966, the spring cereals should be irrigated in the following chronological order: wheat, barley, oats. This result is somewhat surprising since the crops ripened in the reverse order.

P l a c e m e n t o f f e r t i l i z e r. The effect of irrigation on the experimental plots, which had received the fertilizer by broadcasting or, on the other hand, by placement can be compared on the basis of Table 1.

In 1964, the latter irrigation on the three weeks old sprouts, increased the wheat yield by 640 kg/ha or 28 %, when the fertilizer was broadcasted, and the increase in yield produced by irrigation was 530 kg/ha or 22 %, when the fertilizer was placed to the depth of 8—10 cm.

In 1965, the corresponding values were 470 kg/ha or 30 % and 760 kg/ha or 39 %, respectively. Thus, contrary to the results of the former year, the effect of irrigation was better, when the fertilizer was placed into the soil to the depth of 8 cm.

In 1966, more profit from irrigation was obtained, when the fertilizer was broadcasted. Accordingly, the favourable influence of the placement of fertilizer was partly compensated by irrigation. It can be seen, however, that the placement of fertilizer was, without an exception, better than broadcasting of fertilizer.

It is interesting to note that, in 1966, the earliest irrigation, to the 2 ½ weeks old sprouts, reduced most the effect of the placement of fertilizer, while this decrease in effect was the lowest when caused by the latest irrigation, three days after ear emergence. The placement of fertilizer increased the grain yields of all the three cereals about 300 kg/ha, when the irrigation was applied already on the 13th of June, but the increase was even 600 kg/ha when the irrigation was postponed to the 4th of July. This can be also said in another way: The optimum date of irrigation was postponed, when placement of fertilizer was used. This was the result in spite of the fact that the development of plants was speeded up by the placement of fertilizer (Figures 2 and 3).

On the basis of Figure 3 an idea of the importance of placement of fertilizer during a dry early summer can be received. The plant samples were taken from adjoining experimental plots on the 24th of June in 1965 in a way that the position of roots was preserved in the natural state.

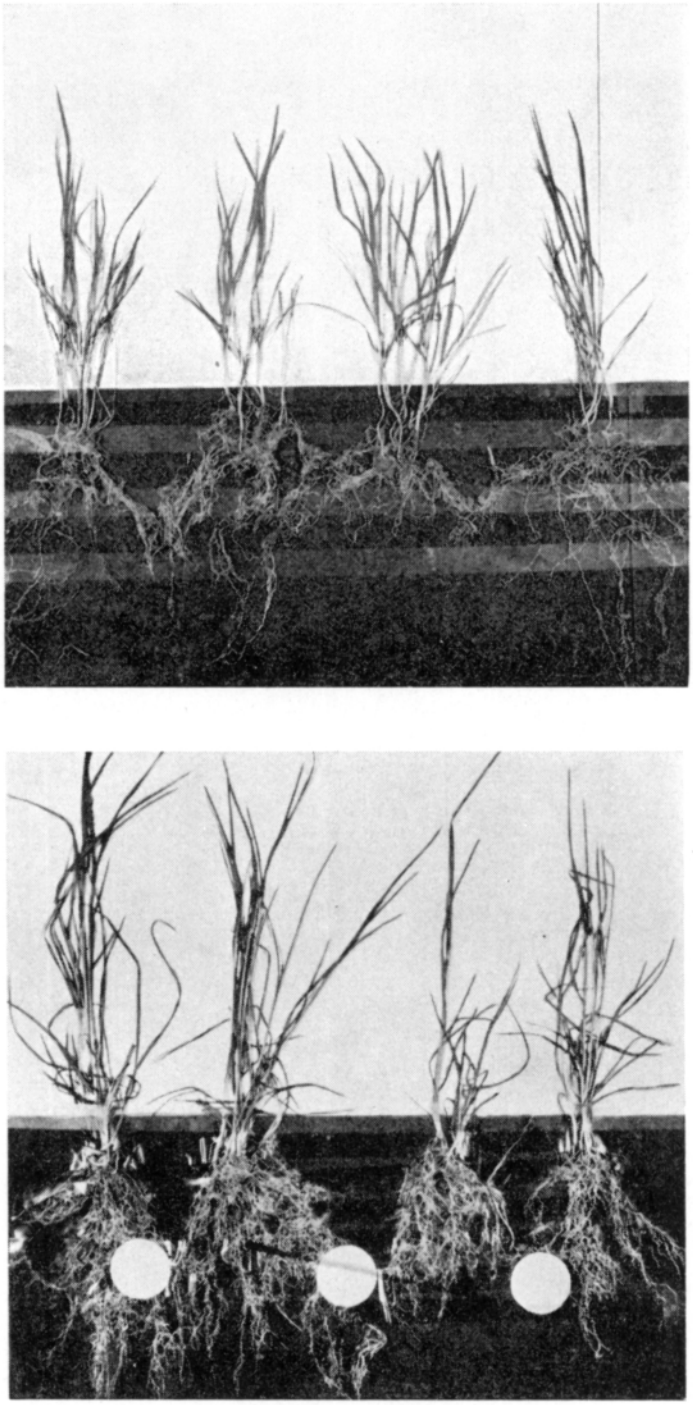


Figure 3. The root system of spring wheat on the 24 the of June 1965. Broadcasting (upper) and placement to the depth of 12 cm (lower) of fertilizer. The position of the placed fertilizer rows marked with white circles.

Table 2. Effect of irrigation at various levels of fertilizer application.

Year	Plant	Fertilizer (8—13—9) kg/ha	Grain yield (moisture 15 %) not irrigated kg/ha	Grain yield (moisture 15 %) irrigated kg/ha	Effect of irrigation kg/ha
1964	Wheat	550	2320	2710	+390
		850	2400	3170	+770
1965	Wheat	500	1600	2170	+570
		1000	1860	2570	+710

The amount of fertilizer applied. In 1964 and 1965, one factor which was coupled to the irrigation experiments, was the amount of compound fertilizer 8—13—9. In Table 2, data of only those irrigations which increased yield, have been recorded. I can be seen that the effect of irrigation in both years was higher, when a greater amount of fertilizer was used. Accordingly, the favourable effect of irrigation was, at least partly, based on the better recovery of fertilizer nutrients by crops.

This fact may be seen more clearly, if the increases in yield which were received with the higher amounts of fertilizer are examined. In 1964, without irrigation, the wheat yield increased only 80 kg/ha, when the amount of fertilizer was raised from 550 kg/ha to 850 kg/ha. With irrigation, this higher amount of fertilizer produced an increase in yield which was even 460 kg/ha. Thus, the use of the higher amount of fertilizer was uneconomical without irrigation. On the other hand, a still heavier application of fertilizer would obviously have been profitable in connection with irrigation. In 1965, an increase of the amount of fertilizer from 500 kg/ha to 1000 kg/ha produced 260 kg more grain per hectar on the plots which were not irrigated, and the corresponding increase in yield was 400 kg/ha on the plots irrigated.

Discussion

Each experimental year, one application of water produced high increases in grain yield. In 1964 and 1965, 35—37 mm of water applied three weeks after sprouting, increased the yields of spring wheat by 600 kg/ha and in 1966, increases of 1000 kg/ha were received, when the sprinklings of 30 mm were carried out 2 ½—4 ½ weeks after sprouting.

On the basis of the results in 1966, the optimum date of irrigation does not seem to depend very closely on the stage of development of the cereal. The effect of irrigation applied 2—5 weeks from sprouting was about equally good. Thus, it can be supposed that also in the former years, the irrigation of the three weeks old sprouts was favourable. In 1966, more profit from irrigation was obtained than in other years because of the drier and warmer growing season. The application of fertilizer was also heavier than in the former years.

The effect of irrigation on the different spring cereals may be well compared, because these crops were growing side by side in the same »sprinkling circles» (Figure 1). The best result with barley and oats was received from irrigation carried out one week before ear emergence. Wheat had no »peak» of this kind. Oats, on the other hand, differed also from barley in being able to make better use of the late irrigation which was applied after ear emergence.

Barley and oats with better specific productiveness profited from irrigation more than wheat when the yields are expressed in kilograms. The relative increase in yield was, however, of the same order with each cereal, or 50 per cent by the irrigation applied at the optimum date.

On the basis of the interaction between the placement of fertilizer, the amount of fertilizer and the irrigation, it seems to be sure that the profitable influence of irrigation was at least partly caused by the better recovery of fertilizer nutrients by plants. As it is known, one important function of water is to dissolve and transfer nutrients for plants.

According to Figure 3, no plant roots are found in the dry surface layer of the soil. On the other hand, the position and movements of nutrients in soil have been investigated in connection with the present field experiments. These investigations, in accordance with previous studies (KAILA and HÄNNINEN 1961) showed that fertilizer which was broadcasted on surface soil stayed almost perfectly immobile and ineffective during dry periods. Thus it is easy to understand that early irrigation was more effective on the plots, which had received fertilizer by broadcasting than by placement. Placement of fertilizer helped the plants to get nutrients also without irrigation as Figure 3 clearly shows. When the drought continued and the soil dried still deeper, the uptake of nutrients by plants became difficult also from fertilizer which was placed into the depth of 8—12 cm. Thus, the results, according to which the placement of fertilizer postponed the best date of irrigation, are easy to understand.

KAILA (1965) has recently pointed out that the recovery of fertilizer nitrogen by cereals is usually less than 50 %. It seems that placement of fertilizer and irrigation are two means with which the recovery of nitrogen and also of other nutrients may be markedly improved. During a dry period these measures are not likely to cancel each others effect, on the contrary, they form a favourable combination. The influence of placement of fertilizer was most effective immediately after sprouting, whereas that of irrigation was at its best a few weeks later, only when a real deficit of water in the root zone began to appear (ELONEN, NIEMINEN and KARA 1967). With these both means the yields were almost doubled in the best cases in 1965 and 1966 (Table 1).

Of course, irrigation may have had also other profitable influences on the plant growth than those based on the better recovery of nutrients. Water in itself is an essential substance of living matter, and it is also in other ways important for plants. Moistening of a dry soil will also cause a sudden increase in microbial activity and mobilization of nutrients (BIRCH 1960, POHJANHEIMO & HEINONEN 1960). The amount of organic material suitable for rapid decomposition by microbes was, however, low in the experimental soils, which had long been cultivated without leys.

If a soil contains plenty of fresh organic material rich in nutrients, it may be possible that irrigation will produce high yields independent on the amount of fertilizer. It is very likely that partly for this reason POHJANHEIMO and HEINONEN (1960) obtained enormous increases in barley yields (3500 kg/ha) with irrigation in the dry summer 1959. The authors consider, however, that the main reason was a different one: When the clay loam was drying, a fairly compact layer on the boundary between plough layer and subsoil hardened, and the plant roots were not able to penetrate this layer before it was moistened by irrigation water. No hard layer of this kind could be observed in our experimental soils.

In addition to POHJANHEIMO and HEINONEN (1960), also KAITERA (1940) and WÄRE (1947) have published results on irrigation of spring cereals in Southern Finland. These authors found that irrigation increased wheat yields only by 300 kg/ha. It must be noticed, however, that fertilizing was scanty, and the amount of water applied at a time was only 20 mm, which is likely to be too low for irrigating of a clay soil. The same concerns also the experiments on oats (KAITERA 1940), in which irrigation increased the grain yields by 500—800 kg/ha.

Irrigation was carried out in the »record experiment» of POHJANHEIMO and HEINONEN (1960) between the 15th of June and the 1st of July. It appears also from the investigations of KAITERA (1940) that the applications of water in the middle and latter part of June were the most effective. On the other hand, WÄRE (1947)got a better result from irrigation carried out one week after sprouting than from that applied two weeks after sprouting. This result which disagrees with those mentioned above and also with our experiments may, for instance, be caused by a poor sprouting and the improving effect of irrigation on sprouting. In Sweden JOHANSSON (1965) has come to the following conclusion: Irrigation of spring cereals must be started, at the earliest, two weeks after sprouting and irrigation must be stopped, at the latest one week after ear emergence. This is perfectly in accordance with our results.

Summary

In the dry summers 1964, 1965 and 1966, irrigation experiments of spring cereals were carried out on clay soils in Southern Finland. The soils having a rather poor structure because of the long-term cultivation without leys, endured without slaking the irrigation which was applied with »slow sprinklers» in the nigh-time. Neutral irrigation water containing small amounts of soluble salts was taken from a brook and a lake.

One irrigation of 30—37 mm, applied at the optimum date, increased the grain yields of spring wheat 600—1000 kg/ha or 25—50 % and those of barley and oats 1600 kg/ha or 50 %. Barley and oats were the experimental plants only in 1966, when the relative increase in yields of all the three cereals were of the same order, namely 50 %.

The optimum date of irrigation did not very closely depend on the state of development of the cereals, since within 2—5 weeks from sprouting about equal increases in yield could be obtained. Barley and oats responded, however, best to the irrigation applied one week before ear emergence. The late irrigation which was applied

three days after ear emergence was best utilized by oats. Thus, the right order to irrigate cereals was in 1966: wheat, barley and oats, in spite of the reverse order of the ripening of the crops. An irrigation at the stage of sprouting had no effect on yield, because the sprouting occured well also without irrigation.

Irrigation produced higher increases in yield when higher amounts of fertilizer were used. Thus, the profitable influence of irrigation was at least partly based on the better recovery of fertilizer nutrients by plants.

Placement of fertilizer into the depth of 8—12 cm postponed the optimum date of irrigation some days, because the crops were able to make use of placed fertilizer also without irrigation in the early part of the summer.

Placement of fertilizer and irrigation together formed an advantageous combination, because the influence of the placement of fertilizer was most effective immediately after sprouting whereas the best period of irrigation began 2—3 weeks later. With these both means, in the best cases, the yields could be almost doubled.

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SELOSTUS:

KEVÄTVILJOJEN SADETUKSESTA ETELÄ-SUOMEN SAVIMAILLA

II. Sadetuksen vaikutuksesta sadon määrään

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Poutavuosina 1964—66 järjestettiin kevätviljojen sadetuskokeita hiesusavimailla Espoossa. Sadetukset suoritettiin heikkotehoisilla ympyräsadettimilla yöaikaan maan pintaa kuorettamatta.

Yksi parhaaseen aikaan suoritettu 30—37 mm sadetus lisäsi vehnäsatoja 600—1000 kg/ha eli 25—50 % sekä ohra- ja kaurasatoja 1600 kg eli 50 %. Ohra ja kaura olivat mukana kokeissa vain v. 1966, jolloin ne hyötyivät sadetuksesta prosenttisesti yhtä paljon kuin vehnäkin.

Paras sadetusaika alkoi noin kaksi viikkoa oraalle tulon jälkeen ja päättyi tähkälle ja röyhylle tulovaiheeseen. Tuona 3—4 viikon aikana sadetuksen onnistuminen riippui paljon enemmän sääoloista kuin kasvien kehitysasteesta. Kevätviljojen oikea sadetusjärjestys näytti olevan: Svenno-vehnä, Ingrid-ohra ja Hannes-kaura siitä huolimatta, että viljat tuleentuivat päinvastaisessa järjestyksessä.

Sadetus antoi suurempia sadonlisiä käytettäessä runsaampia lannoitemääriä. Sadetuksen edullinen vaikutus perustui siten ainakin osittain väkilannoitteiden parantuneeseen hyväksikäyttöön.

Lannoitteiden sijoittaminen 8—12 cm syvyyteen näytti siirtävän parasta sadetusajankohtaa hieman myöhäisemmäksi, koska kasvit pystyivät alkukesällä käyttämään sijoitettua lannoitetta sadettamattakin. Sijoituslannoitus ja sadetus muodostivat edullisen yhdistelmän, sillä sijoituslannoitus vaikutti tehokkaimmin heti oraalletulon jälkeen, kun taas paras sadetusaika alkoi 2—3 viikkoa myöhemmin. Yhdessä nämä kaksi keinoa kohottivat viljasatoja parhaissa tapauksissa lähes kaksinkertaisiksi.