SPRINKLER IRRIGATION ON CLAY SOILS IN SOUTHERN FINLAND

III. Effect on the quality of grain yield

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According to the previous papers (ELONEN, NIEMINEN and KARA 1967 a, b) spring cereals suffered from a serious shortage of water during the dry summers 1964, 1965 and 1966 when growing on clay soils in Southern Finland. One irrigation applied at the optimum date and using a suitable technique produced also high increases in yield. Increases in wheat yield were 600—1000 kg/ha or 25—50 % and in 1966, those of barley and oats were even 1600 kg/ha or 50 %.

It may be supposed that a factor which has so great effect on the quantity of the grain yield is likely to have an influence also on its quality. Therefore, some analyses of the grain were carried out. Attention was particularly paid to the quality of the yield in 1966, which experimental year was the most interesting one. Then the weather conditions and the experimental procedure made it possible to study the date of irrigation which is likely to have a decisive effect on the quality of the grain yield.

Methods

Differences in ripening of the grain was studied by analysing their moisture content at the harvest. The representative samples taken from the fresh yields of each plot were first air-dried. Thereafter 2 g of ground grain was dried for one and a half hour at 105°C.

The hectoliter weights were determined from air-dry, unsorted grain. Though the amount of screenings was scanty, a little lowering of hectoliter weights for this reason is possible. On the other hand, the moisture of grain was lower than normal, or 10—12 %.

1000-grain weights were determined from healthy grains at least one half in size. The weights were calculated to correspond to the moisture of 15 per cent.

Light green grains, even oat grains with only a greenish head, were included in green grains.

The quality of wheat starch (amylase activity) was estimated with the falling-number method (OLERAD 1964). For determination of crude protein the total nitrogen was analysed by Kjeldahl method. The total nitrogen content of wheat and barley was multiplied with 6.25 and that of oats with 5.7. The results were expressed as per cents of dry matter.

Table 1. The effect of irrigation on the quality of grain yield.

Year Plant	Irrigation date	Irrigation amount mm	Moisture at harvest %	Green grains %	1000-grain weight %	Hl-weight kg	Falling number	Crude protein % of DM	Grain yield kg/ha
1964	—	—	26.8			76.6		17.0	2360
Wheat	23. 6.	35	27.2			76.1		14.7	2940
		L.S.D.	0.3					0.4	140
1965	—	—	30.4			71.2	229	15.8	1740
Wheat	18. 6.	37	28.1			71.4	274	14.5	2360
		L.S.D.	0.7				14	0.5	150
1966	—	—	22.9	0.5	37.8	77.5	188	16.8	2100
Wheat	13. 6.	30	22.5	0.6	37.9	77.7	216	13.8	3180
	19. 6.	30	20.6	0.3	36.8	78.6	229	13.6	3170
	26. 6.	30	22.9	2.1	35.4	76.7	224	14.0	3100
	4.7	35	26.3	3.5	37.7	74.5	182	15.8	2700
		L.S.D.	1.8	0.5	0.9	0.8	17	0.6	250
1966	—	—	16.3	1.1	49.2	68.0		13.4	3040
Barley	13. 6.	30	14.5	0.7	49.5	68.7		11.4	4280
	19. 6.	30	14.7	0.4	48.2	69.0		10.8	4140
	26. 6.	30	19.4	1.1	46.8	68.0		11.1	4650
	4. 7.	35	24.0	10.5	47.3	66.8		12.0	3760
		L.S.D.	1.5	1.7	1.0	0.8		0.9	480
1966	—	—	16.5	4.9	31.2	52.2		14.7	3300
Oats	13. 6.	30	14.8	2.6	30.8	53.1		12.8	4360
	19. 6.	30	14.8	3.0	32.1	53.6		13.3	4410
	26. 6.	30	20.7	9.3	31.3	51.5		12.5	4870
	4. 7.	35	22.7	14.4	32.2	51.2		13.0	4450
		L.S.D.	0.9	1.7	1.1	1.0		0.7	400

Results

The date of irrigation. The effect of the irrigation date on the quality of grain yield can be seen from Table 1. Data of only those irrigations in 1964 and

1965 which increased yield have been recorded. It must be emphasised that each year irrigation was applied only once, on different plots at different dates.

The moisture of grain at the harvest can be considered as a measure of ripening. In 1964, the effect of irrigation was very little. 35 mm of water applied on the 23th of June caused an increase of 0.4 per cent units in the moisture of grain (from 26.8 % to 27.2 %). Accordingly, the ripening of wheat was a little retarded by irrigation. In 1965, ripening was, on the contrary, speeded up by the irrigation of 35 mm which was applied on the 18th of June. The grains from the irrigated plots were 2.3 per cent units drier than those from the plots not irrigated (from 30.4 % to 28.1 %). This difference in moisture corresponds to the difference of a few days in ripening.

These somewhat contradictory results can be explained in the light of the results in 1966. The ripening of both wheat, barley and oats was speeded up by the early applications of water carried out on the 13th and 19th of June. The moisture of the grains at the harvest was about two per cent units lower on the plots irrigated than on those not irrigated. On the contrary, when irrigation was applied later, on the 26th of June and on the 4th of July, the ripening of the cereals was retarded. Particularly, the irrigation applied after ear emergence had a very unfavourable influence. It increased the moisture of wheat 3.4 per cent units (from 22.9 to 26.3), that of barley 7.7 per cent units (from 16.3 to 24.0) and that of oats 6.2 per cent units (from 16.5 to 22.7). It seems that the ripening of barley and oats was more retarded by the late irrigation than that of wheat.

Consequently, the ripening of the cereals was speeded up by early irrigation. The transitional period when irrigation had no effect on ripening was about two weeks before ear emergence or about Midsummer.

The early irrigations (before Midsummer) had no great influence on the amount of green grains in 1966. On the other hand, the late irrigations (after Midsummer) and particularly the one applied after ear emergence, markedly increased the number of green grains. According to the observations made in the field, green grains were derived from adventitious shoots. This indicates that the irrigation applied after ear emergence, caused tillering and these adventitious shoots had not time to ripen. The tillering of wheat was, according to the results in Table 1, less than that of barley and oats.

When examining the 1000-grain weights a surprising observation can be made: Irrigation did not increase the weight of grains, though it increased the yield. On the contrary, the grains from the irrigated plots were somewhat smaller than those from the plots not irrigated. Differences in the 1000-grain weights are, however, small, even if statistically significant differences exist.

Irrigation had a very small effect on the hectoliter weights in 1964 and 1965. However, according to the results of the year 1966, the second irrigation slightly increased the hectoliter weights, whereas they were decreased by the last irrigation. This late irrigation, after ear emergence, lowered most the hectoliter weight of wheat, from 77.5 to 74.5 or 3 kg. Hectoliter weights were normal in 1964 and 1966, but in 1965 they were low.

The falling number which will indicate the quality of wheat starch was fairly high in the years 1965 and 1966. Irrigation exerted a favourable effect by increasing

the falling number about 40 units in both years. The determination was not carried out in 1964. Also the late irrigation, applied after ear emergence, did not significantly lower the falling number, though it had in other respects an impairing effect on the grain quality.

Particularly important is to note that each year, irrigation decreased the crude protein content of grain, even to a marked extent. The crude protein content of wheat was lowered 2.3 per cent units (from 17.0 to 14.7) in 1964 and 1.3 per cent units (from 15.8 to 14.5) in 1965. In 1966, the effect of the irrigation which was applied either on the 13th, 19th or 26th of June, was even greater: The decrease in the crude protein content of wheat was, in average, 3 per cent units (from 16.8 to 13.8), that of barley 2.3 per cent units (from 13.4 to 11.1) and that of oats 1.8 units (from 14.7 to 12.9). The late irrigation (on the 4th of July) had a smaller effect.

P l a c e m e n t o f f e r t i l i z e r. The placement of fertilizers down to the depth of 8—12 cm had an effect not only on the quantity of grain yield but also on

Table 2. Effect of irrigation and placement of fertilizers. B = broadcasting of fertilizers. P = placement of fertilizers.

Year Plant	Irrigation date	Irrigation amount mm	Moisture at harvest (%) B	Moisture at harvest (%) P	Hectoliter weight (kg) B	Hectoliter weight (kg) P	Crude protein % of DM B	Crude protein % of DM P
1964	—	—	27.7	26.0	76.6	76.6	17.4	16.6
Wheat	23. 6.	35	28.0	26.3	76.0	76.1	15.1	14.3
1965	—	—	31.3	29.1	69.5	72.9	15.9	15.7
Wheat	18. 6.	37	28.8	27.2	69.7	73.0	14.8	14.3
1966	—	—	23.5	22.3	77.2	77.9	17.6	16.0
Wheat	13. 6.	30	22.8	22.3	77.6	77.8	14.0	13.6
	19. 6.	30	21.1	20.0	78.4	78.9	13.8	13.5
	26. 6.	30	23.4	22.4	76.4	77.0	14.2	13.7
	4. 7.	35	28.3	24.3	73.0	76.1	16.1	15.4
		L.S.D.	2.7	2.7	1.2	1.2	1.0	1.0
1966	—	—	17.3	15.3	68.4	67.6	13.6	13.1
Barley	13. 6.	30	14.9	14.1	68.9	68.5	11.9	10.9
	19. 6.	30	15.3	14.1	69.1	68.8	11.0	10.7
	26. 6.	30	21.0	17.8	68.0	68.0	11.4	10.8
	4. 7.	35	27.6	20.3	66.0	67.5	12.2	11.9
		L.S.D.	2.2	2.2	1.2	1.2	1.3	1.3
1966	—	—	17.7	15.4	52.0	52.4	14.8	14.5
Oats	13. 6.	30	15.1	14.5	53.1	53.2	12.9	12.8
	19. 6.	30	15.1	14.4	53.8	53.4	13.2	13.3
	26. 6.	30	22.2	19.1	51.4	51.6	12.5	12.5
	4. 7.	35	23.9	21.5	50.6	51.8	13.0	13.0
		L.S.D.	1.3	1.3	1.6	1.6	1.1	1.1

its quality. The interaction between irrigation and placement of fertilizers on the moisture, on the hectoliter weights, and on the crude protein content of grain can be seen from Table 2.

Without an exception, the placement of fertilizer decreased the moisture of grain at the harvest time i.e. it speeded up ripening. The effect of placement of fertilizers was particularly profitable when the irrigation was applied too late. In 1966, the irrigation applied three days after ear emergence, increased the moisture of barley as much as 10.3 per cent units (from 17.3 to 27.6), if the fertilizers were broadcasted, but the increase was only 5.0 per cent units (from 15.3 to 20.3), if the same amount of fertilizers was placed into the soil. Thus, the placement of fertilizers decreased the unprofitable effect of the too late irrigation. This fact may be also seen, even if not equally distinctly, in regard to the moisture contents of wheat and oats. On the other hand, irrigation applied at a suitable date and placement of fertilizers, both for their own part, speeded up ripening. Together they decreased the moisture of wheat 4.1 per cent units (from 31.3 to 27.2) in 1965 and 3.5 per cent units (from 23.5 to 20.0) in 1966. The decreases in the moisture of barley and oats in 1966 were 3.2 (from 17.3 to 14.1) and 3.3 per cent units (from 17.7 to 14.4), respectively. Accordingly, the numbers are of the same order, and they indicate an advancement in ripening of several days.

The amount of green grains was also decreased by the placement of fertilizers (these data are not recorded in Table 2).

Further, the placement of fertilizers had a favourable effect on the hectoliter weights. Also this effect was particularly marked, if irrigation was carried out too late. For instance, in 1966, the irrigation applied after ear emergence, decreased the hectoliter weight of wheat by 4. 2 kg (from 77.2 to 73.0), if the fertilizers were broadcasted, but only by 1.8 kg (from 77.9 to 76.1), if the fertilizers were placed.

The effect of placement of fertilizers on the size of grains and on the falling number of wheat was low, and its advantage was apparent only when irrigation had been applied after ear emergence.

The crude protein content of grains was decreased by both irrigation and the placement of fertilizers. Owing to the combine effect of those factors in 1966, the decrease in the crude protein content of wheat was as much as 4 per cent units (from

Table 3. Effect of irrigation at various levels of fertilizer application.

Year Plant	Fertilizer (8—13—9) kg/ha	Moisture at harvest (%) not irrig.	 irrigated	Hectoliter weight (kg) not irrig.	 irrigated	Crude protein % of DM not irrig.	 irrigated
1964	550	26.6	26.9	76.6	75.9	16.9	14.5
Wheat	850	27.0	27.3	76.6	76.2	17.0	14.8
1965	500	30.4	28.1	71.5	71.6	15.7	14.4
Wheat	1000	30.3	28.2	71.0	71.1	16.0	14.6

17.6 to 13.6), that of barley 2.8 per cent units (from 13.6 to 10.8) and that of oats 2.0 per cent units (from 14.8 to 12.8). In the former years, the results were of the same kind.

The amount of fertilizers applied. The amount of fertilizers was included in the experiment only in 1964 and 1965.

No interaction between irrigation and the amount of fertilizers on the ripening, on the hectoliter weights and on the crude protein content of wheat appeared (Table 3), though this interaction on the amount of wheat yield was very significant.

The level of fertilizers in itself had also only a slight effect on the quality of wheat. This was statistically significant only in regard to the crude protein content which was somewhat increased by the higher amounts of fertilizers.

Discussion

According to the present results the ripening and quality of grain yield are highly dependent on the date of irrigation. There is a distinct period, before which irrigation will speed up ripening and improve the quality of grains and after which, on the contrary, ripening is retarded and the quality of grain yield impaired by irrigation.

Irrigation increased the yield markedly, but it did not increase the weight of individual grains. Accordingly, the number of grains was increased by irrigation. The field observations and the estimation of green grains indicated that the increase in the number of grains was mainly caused by tillering. At the harvest, plenty of green adventitious shoots existed on the plots irrigated late. It can be well supposed that also other applications of water produced adventitious shoots, which had time to ripen, if the irrigation was applied at a sufficiently early stage of development.

The tillering was obviously caused by »the fertilizing effect» of irrigation. In the previous paper (Elonen, Nieminen and Kara 1967 b) it was pointed out that the effect of irrigation was to a noticeable degree based on the better recovery of fertilizer nutrients. Moistening of a dry soil will also cause a sudden increase in microbial activity and mobilization of nutrients (Birch 1960, Pohjanheimo and Heinonen 1960). Obviously, the earlier the stage of growth is when these reserves of nutrients and particularly those of nitrogen become available to plants, the earlier and the more uniformly the crops will ripen and the better quality of grain will be obtained.

During the short growing season in Finland serious attention to the ripening of crops must be paid. Pohjanheimo and Heinonen (1960) obtained, with the aid of irrigation, very high increases in barley yields in the dry summer 1959. However, they write: »It seems unavoidable at all events that any attempts to achieve high yield level with the aid of irrigation in Finland are accompanied by the risks introduced by too late ripening». Symptoms of the lack of water appeared already in the beginning of June in that unusually early growing season, but the irrigation was applied not until at the latter part of June. Because of irrigation the ripening was retarded about ten days. According to the present study, it seems that, if the irrigation had been applied about two weeks earlier, the ripening would have been speeded up without decrease in yield.

If attention is only paid to the yield level, the optimum period of irrigation began about two weeks after sprouting and ended at the stage of ear emergence (ELONEN, NIEMINEN and KARA 1967 b). The length of this period was 3—4 weeks. If attention is also paid to the ripening and to the quality of grain yield, irrigation had to be applied, at the latest, about two weeks before ear emergence. Accordingly, the optimum period of irrigation, in regard to both the yield level an to its ripening and quality, was in the middle between sprouting and ear emergence and its length was about two weeks.

With the aid of placement of fertilizers, the optimum period of irrigation may be postponed. The level of fertilizing had, however, no great influence on the ripening and on the quality of yield.

The crude protein content of grains requires a chapter by itself. It seemed not to be dependent on the date of irrigation, but on the amount of yield. If the crude protein contents are compared with the yield (Table 1), it may be seen that they are usually the lower the higher yields were obtained. Thus, the crude protein content was most decreased by those applications of water which produced the highest yields.

The value of wheat, oats and fodder barley are markedly decreased by this high loss of crude protein. Irrigation seems, however, to be an excellent means to the grower of malting barley: Without irrigation barley did not qualify for malting barley. With irrigation the crude protein content was sufficiently decreased (the upper limit of the required qualification is 12 per cent) and higher yields were obtained at the same time.

The decrease of the crude protein content of grains was likely to be caused by the shortage of nitrogen. In 1966, the grain yields of both wheat, barley and oats from the plots irrigated, contained more nitrogen than applied as fertilizers. Because also nitrogen of straw and roots must be included, it may be seen that the plants were, to a considerable degree, forced to resort to the natural nitrogen recources of the soil. Under long-term cultivation without leys, these natural nitrogen resources were, however, obviously scanty in the experimental soils. Thus, the occurring of a shortage of nitrogen is easy to understand.

In the experiment of POHJANHEIMO and HEINONEN (1960) irrigation had no great effect on the crude protein content of barley, though it increased the yield markedly. Obviously, the soil contained an abundance of natural resources of nitrogen, the mobilization of which was effectively stimulated by irrigation. The preceding crops in this experiment were turnip rape and three years old clover ley.

The effect of irrigation on the crude protein content of grains is likely to be decisively dependent on the nitrogen resources of the soil. If they are scanty, there may be response to nitrogen fertilizing. The influence of the amount of fertilizers on the crude protein content of wheat was apparent also in the present experiments (Table 3). Yet, this influence was not high because of the relative low nitrogen dressings which were partly consumed by the increases in yield. HUTCHEON and PAUL (1966) suppose according to their investigations that, by regulating soil moisture conditions and the rate of fertilizer nitrogen, it is possible to obtain the wanted crude protein content of wheat with an accurary of 0.5 per cent units.

Summary

In the present paper the effect of irrigation on the ripening and on the quality of grain yield in the dry summers 1964—1966 was studied. Both the ripening and the quality of grain were found to be highly dependent on the date of irrigation. There was a distinct transitional period, before which irrigation speeded up ripening, decreased the amount of green grains and improved hectoliter weights and »falling numbers». On the contrary, if irrigation was applied after this transitional period, ripening was retarded and the quality of grains was impaired in regard to these properties. This transitional period was in the experimental years about two weeks before ear emergence or about Midsummer. The optimum period of irrigation, in regard to both yield level and to its ripening and quality, was in the middle between sprouting and ear emergence and its length was about two weeks. Wheat, barley and oats all responded to the date of irrigation in about the same way.

The placement of fertilizers into the depth of 8—12 cm speeded up ripening and improved hectoliter weights. Particularly, it decreased the unfavourable effect of too late irrigation. The rate of fertilizers had no great influence on the quality of grains.

Irrigation did not increase the weight of grains, but it increased the number of grains. The main effect of irrigation was likely to be caused by the tillering of crops, and these adventitious shoots had time to ripen, if irrigation was applied at a sufficiently early stage of development.

The crude protein content of both wheat, barley and oats was markedly decreased by irrigation independently of the date of it. This decrease was usually the greater the higher yield was obtained. The decrease in the crude protein content indicates a shortage of nitrogen which was likely to be caused by the scanty mobilizeable resources of nitrogen in the soils long cultivated without leys. Obviously, this unfavourable decrease in the crude protein content could have been prevented with heavy dressings of fertilizer nitrogen.

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SELOSTUS:

KEVÄTVILJOJEN SADETUKSESTA ETELÄ-SUOMEN SAVIMAILLA

III. Sadetuksen vaikutuksesta sadon laatuun

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Helsingin yliopiston maanviljelyskemian laitos

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Poutavuosina 1964—1966 runsaasti kevätviljasatoja kohottaneet sadetukset vaikuttivat myös sadon tuleentumiseen ja laatuun. Sadetuksen ajankohdan havaittiin olevan avainasemassa. Saatiin esille selvä taitekohta, jota ennen suoritettu sadetus edisti tuleentumista, vähensi vihreiden jyvien määrää sekä paransi hehtolitrapainoa ja sakolukua. Sensijaan, jos sadetus annettiin tuon taitekohdan jälkeen, tuleentuminen viivästyi ja sadon laatu heikkeni näiden ominaisuuksien osalta. Tämä taitekohta osui koevuosina noin kaksi viikkoa ennen tähkälle ja röyhylle tuloa eli juhannuksen paikkeille. Mahdollisimman runsaan ja samalla kertaa aikaisin tuleentuvan ja hyvälaatuisen sadon saavuttamiseksi sadetus olisi pitänyt suorittaa kahden viikon aikana orastumisen ja tähkälletulon puolivälissä eli kesäkuun toisella tai kolmannella viikolla. Sekä vehnä, ohra että kaura suhtautuivat sadetuksen ajankohtaan suunnilleen samalla tavalla.

Lannoitteiden sijoittaminen 8—12 cm syvyyteen edisti tuleentumista ja kohotti hehtolitrapainoa. Erityisesti se pienensi myöhäisen sadetuksen haitallista vaikutusta. Käytettyjen lannoitemäärien vaikutus laatuun oli hyvin vähäinen.

Vaikka sadetus kohotti huomattavasti satoa, jyväkoko ei suurentunut. Sadetus lisäsi siten jyvien määrää, todennäköisesti pääasiassa uusia versoja muodostamalla, ja nämä jälkiversot ehtivät tuleentua, mikäli sadetus suoritettiin riittävän aikaisin.

Jyvien proteiinipitoisuutta sadetus alensi huomattavan paljon jokaisen viljakasvin osalta sadetusajankohdasta riippumatta. Alennus oli yleensä sitä suurempi mitä suurempi sato saatiin. Todennäköisesti tämä johtui lähinnä nurmettomina viljeltyjen koemaiden mobilisaatiokykyisten typpivarojen niukkuudesta. Runsaammalla typpilannoituksella proteiinipitoisuuden haitallista alenemista olisi luultavasti voitu estää.