SPRINKLER IRRIGATION ON CLAY SOILS IN SOUTHERN FINLAND

I. Sprinkler irrigation, its technique and effect on soil moisture

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Received March 2, 1967

Sprinkler irrigation of spring cereals on a clay soil may fail, if sufficient attention is not paid to the technique used. An unsuitable application of water may destroy the porous structure of the soil, which is essential for good growth on clay soils.

The water stability of a dry soil aggregate is largely dependent on the wetting rate (SILLANPÄÄ 1959); therefore, it is necessary to irrigate with caution clay and silt soils having a poor structure. Particularly, the first phase of irrigation is important, since a too rapid intake of water is likely to cause unequal swelling and to break up aggregates (DETTMANN 1958). The mechanical impact of falling drops of water will destroy aggregation, too: thus, the size of drops is also significant.

The intensity and uniformity of sprinkler irrigation and the size of drops are dependent on the equipment used. The soils with a poor structure should be irrigated with the so-called »slow sprinklers». If the surface of the soil is protected against slaking by vegetation, more intensive sprinkling may be used, provided the permeability of the soil is high.

The weather conditions have also an effect on the success of the sprinkler irrigation. The warmer, the windier and the drier the weather is, the larger part of the irrigation water will evaporate directly up to air. In Sweden HALLGREN and JOHANSSON (1958) have proved that from sprinkler irrigation carried out in the daytime often one third is lost, but evaporation in the night is less than 5 per cent. An advantage of irrigating by night is also the better uniformity obtained. Because the wind usually calms down for the night, the sprinkling will be more regular and the water will distribute as evenly as it is possible with the sprinklers used.

Attention must also be paid to the quality of irrigation water. Temperature is not considered to be of importance, because it is supposed that the water drops will adopt the temperature of air before falling to the ground (LAVERTON 1964, p. 114). A high content of water soluble salts is detrimental. Especially sodium salts will destroy soil structure in comparatively low concentrations (CZERATZKI 1961). A high concentration of salts in itself disturbs the growth of plants. Water containing industrial or sewage residues may also be unsuitable for irrigation.

In Finland, very few investigations have been published concerning the irrigation of cereals (KAITERA 1940, WÄRE 1947, POHJANHEIMO and HEINONEN 1960). The great significance of this subject cannot be denied, because, usually, the drought of early summer markedly decreases yields in Southern Finland, the most important grain cultivating area of our country (POHJANHEIMO 1959). Generally, our water sources may be suitable for irrigation; the waters from the regions of sulphate soils and acid moors might be exceptions. The soil, however, has great demands on the technique of irrigation: In the southern parts of our country, where the highest profit from irrigation could be expected, the main textural fractions are clay and silt which do not take heavy irrigation or natural rains without crust formation. This is likely to be a reason for some unsatisfactory results obtained on farms and experimental fields.

During the last three years, 1964—66, experiments on sprinkler irrigation of spring cereals have been carried out in the fields of Pakankylä farm (in the neighbourhood of Helsinki) owned by the Research Foundation for Agricultural Machinery. The effect of irrigation on the yields has been the main subject, but the uniformity of sprinkler irrigation and the effect of irrigation on the soil moisture conditions have also been studied. In this paper, the results of these last-mentioned observations are reported.

Soils and weather conditions

The irrigation water was taken from a brook running through the fields and in 1964 from a lake in the woods. pH of the river water was 7.0 and the amount of soluble salts expressed by electrical conductivity 68 μmho per cm. The lake water was of the same quality.

The experimental soils were silty clay. The average particle size distribution and the content of organic carbon of the soils are reported in Table 1. Figure 1 represents the pF-curves of soil material passed 2 mm. The water-holding properties of the soils seem to be particularly favourable to plants. Although the gravimetric analyses performed at the field point out that the pF-curves of the soils in natural state would be somewhat steeper, the soils are, in any case, capable of storing plenty of water available for plants.

Consequently, the experimental soils are not likely to be particularly sensitive to drought. On the other hand, the long-term cultivation without leys had detiorated the soil structure. Probably, the soils are more inclined to get crusted by rain or irrigation than the average clay soils in Southern Finland.

Table 1. Mechanical composition and content of organic carbon of the experimental soils.

Year	Depth cm	Particle size fractions, % <2 μ	2–20 μ	20–200 μ	>200 μ	Org. C %
1964	0–20	37	44	15	4	3.2
	25–35	40	42	15	3	–
1965–66	0–20	47	36	13	4	4.0
	40–60	66	24	10	0	0.5

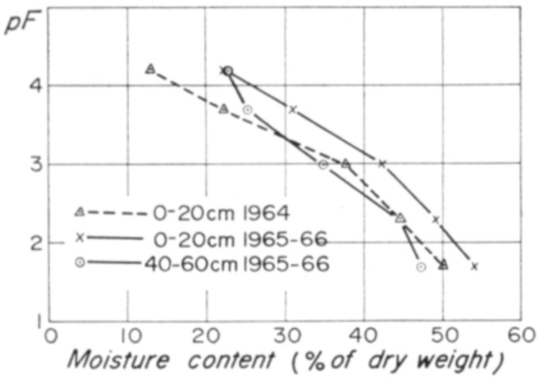

Figure 1. pF-curves of the soil material (< 2 mm).

In 1964—66 the experimental plant was spring wheat, in 1966 also barley and oats were included. The early part of the growing seasons in these years was drier than normal, in 1966 also exceptionally warm (Table 2). Therefore, there is good reason to speak of »irrigation summers».

Methods

The irrigation was performed by rotary sprinklers, in 1964—65 was used »Bauer B 70» with one nozzle and in 1966 »Perrot Z A 30 D» with two nozzles, into which

Table 2. Temperature and precipitation during the growing seasons at the experimental field (P) and in Tikkurila (T), 20 km east of it.

Month	Temperature, °C 1964 (T)	1965 (T)	1966 (P)	Average 1921–50 (T)	Precipitation, mm 1964 (P)	1965 (P)	1966 (P)	Average 1921–50 (T)
V	9.5	6.8	7.1	9.0	39	19	12	49
VI	14.8	15.1	18.1	13.5	22	32	19	52
VII	16.4	14.4	18.5	16.7	24	159	52	67
VIII	14.5	14.1	14.1	15.0	91	98	58	77
IX	10.0	12.5	–	10.7	–	61	–	72

water was conducted through pipelines and plastic tubes. Working pressure was 2.5 kp/cm², the radius of sprinkling circles 12±2 m and the rate of application 2.5—4 mm per hour.

The sprinkling was performed in calm nights between 20 and 06 o'clock. From 22 to 04, the relative humidity of air was 90—100 %, though it was lower in the beginning and at the end of the irrigation period. The temperature of the irrigation water varied between 14 and 21°C.

The amount of water received by every sprinkling circle was controlled: 400 ml plastic flasks with funnels (9 cm in diameter) were placed at definite distances from the sprinklers. The water accumulated into the flasks was measured with a graduated cylinder. The sprinklers were stopped one by one as soon as the irrigation state wanted was reached. The application of water was usually 30—37 mm. The experimental soils endured the irrigation every time without slaking.

The variations in soil moisture content during the growing seasons were followed by the measurements with plaster of paris blocks (BOUYOUCOS 1954). The blocks were inserted in the soil after sowing when the soil had become dry only in the surface layer. It was tried to get them into good contact with the soil and to disturb the soil structure as little as possible. A bore one inch in diameter and a small spade were used as tools. If the density of the plant cover above the blocks was not normal, the measurements were discarded. 24 gypsum blocks were placed in the experimental field in 1964, 48 blocks in 1965 and 51 blocks in 1966. To control the measurements, gravimetric analyses of soil moisture content were made.

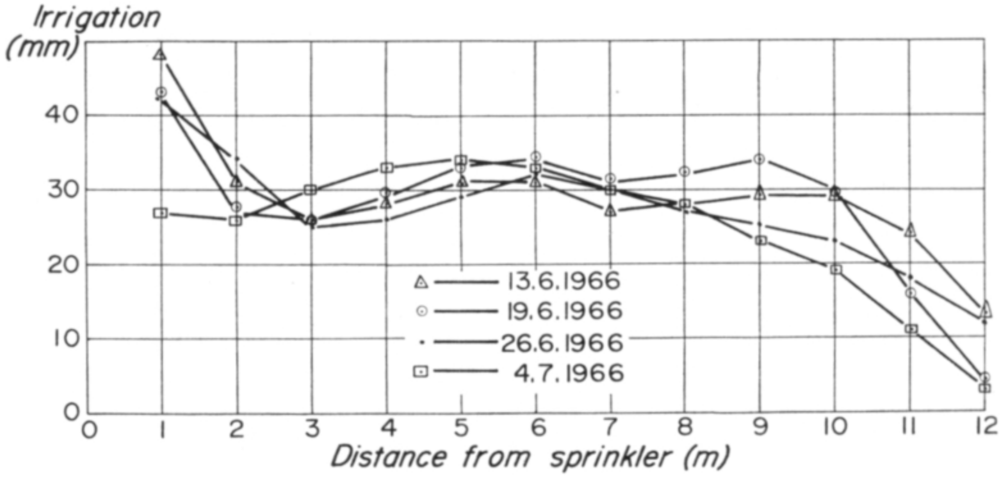

Figure 2. Uniformity of 30 mm of sprinkler irrigation applied in the nighttime in 1966.

Results

T h e u n i f o r m i t y o f s p r i n k l e r i r r i g a t i o n. Figure 2 represents the average distribution of water by the sprinklers in 1966. Three zones may be found:

1. At the distance of 0—1½ m from the sprinklers more than the average amount of water was accumulated.

2. At the distance of 2 to 9 m the sprinklers distributed the water fairly uniformly, so that when the irrigation was 30 mm, the amount of water varied between 25 and 35 mm.

3. The outermost zones of the irrigation circles got the lowest amounts of water.

The sprinklers used in the years 1964 and 1965 had one nozzle with one opening and the water jet was too violently distributed by the swing arms of the sprinklers. The nearest surroundings of the sprinklers to the distance of 5 meters got too much water and at the distance of 2 meters the amount of water could be twice the average. The sprinklers used in 1966 had two nozzles, which distributed the water in two opposite directions. Only one of the two water jets was spread by the swing arms. Beside the sprinklers less water was accumulated than in the former years and the irrigation became more uniform.

Table 3. Dry periods. Available water at the depth of 20 cm of the soil not irrigated: a) less than 50 %, b) 0—10 % of the total.

Growing season (sowing — harvest)		Dry periods	Number of days
1964 (22. 5.—25. 9.)	a	16. 6.—31. 7. and 10. 8.—29. 8.	64
	b	5. 7.— 8. 7. and 15. 7.—31. 7.	19
1965 (12. 5.—25. 9.)	a	9. 6.— 7. 7.	28
	b	20. 6.—30. 6.	10
1966 (15. 5.—25. 8.)	a	13. 6.—12. 8.	60
	b	19. 6.—31. 7.	42

The influence of sprinkler irrigation on the soil moisture conditions. In each experimental year, without irrigation the available water in top soils decreased to less than 50 % of the available water capacity (Table 3). This happened during the second or third week in June, i.e. 2—3 weeks after sprouting. If this 50 % is considered the limit of water deficit, the spring cereals suffered a lack of water during two months in the years of 1964 and 1966, and one month in 1965. The soils were near the wilting point for relatively long periods, in 1966 even for six weeks. The influence of transpiration was found to be marked also in the deeper layers of soil in 1964 and 1966.

Concerning the following results, it is important to keep in mind that water was applied to each irrigated plot only once, to different plots at different dates.

In 1964 15 mm of water was applied at the stage of sprouting, or on the 30th of May. At this time, only the surface layer of soil was dry and the irrigation had no effect on the moisture at the depth of 20 cm. It is likely that this lot of water was mostly wasted by evaporation.

On the 23th of June, or 18 days before the ear emergence, 35 mm of water was applied to the plots, which had not been irrigated at the first time. About one week earlier, the available water at the depth of 20 cm was only 50 % of its total capacity, and up to the date of irrigation the reserves of available water at the depth of 35 cm had also decreased by half. This fairly high amount of irrigation water moistened the top soil to the field capacity and considerably increased the readings of the gypsum blocks also at the depth of 35 cm. The profitable influence of the irrigation on the soil moisture conditions lasted about two weeks. After that the irrigated plots dried somewhat quicker throughout the soil profile down to the depth of 65 cm than did those not irrigated.

In 1965, the first irrigation was applied on the 18th of June, or 24 days before the ear emergence. Then, the amount of available water at the depth of 20 cm had already for 1 ½ weeks been less than 50 %, and up to the date of irrigation the top soil had dried almost to the wilting point. At the depth of 35 cm, however, 80 % of the available water was left. 37 mm of irrigation water plus 4 mm of natural rain moistened the top soil up to the field capacity, but the readings of the gypsum blocks at the depth of 35 cm increased only with 5 per cent. There was not time to use up this amount of irrigation water, because of the rainy and cloudy period which started less than two weeks later and continued for almost the whole latter part of the summer.

On July 2nd 1965, or 10 days before the ear emergence, 37 mm of water was applied in spite of the natural rains. Because the rains continued, this irrigation lost its significance. The precipitation during the first ten days of July was 60 mm and that of the whole July 159 mm. Since the second week of July the experimental soil actually reached the field capacity and in the latter part of the summer the plants were likely to suffer from the lack of air.

In 1966, attention was mainly paid to the date of irrigation. At the intervals of about one week, four sprinklings were carried out. The first one was started when the amount of available water was lowered to 50 per cent of the total capacity.

The soil moisture conditions and the rate of the water uptake by plants during this exceptionally warm and dry growing season may be seen from Figure 3. There are reasons to suppose that the influence of the third irrigation was not reliably measured. Probably, it was of the same order as that of the first two sprinklings.

In the first place, attention must be paid to the drying of the soil not irrigated: At the depths of 10 and 20 cm the soil dried at almost equal rapidity. Thus, the water consumption by plant roots was fairly equal throughout the top soil. At the depth of 40 cm the soil dried markedly slower. On the 20th of June, or 11 days before ear emergence, when the top soil reached the wilting point, the soil at the depth of 40 cm was continuously in the field capacity. One month later the available water at that depth was used up, too.

30 mm of water applied by sprinkler irrigation at the first dates (K_1 and K_2) moistened the soil to the field capacity at the depth of 10 cm, but not entirely at the depth of 20 cm. The fourth application of water (K_4) was not sufficient to raise the readings of the gypsum blocks at the depth of 20 cm more than to the level of 50 % of the available water capacity, though the amount of water was 35 mm. In

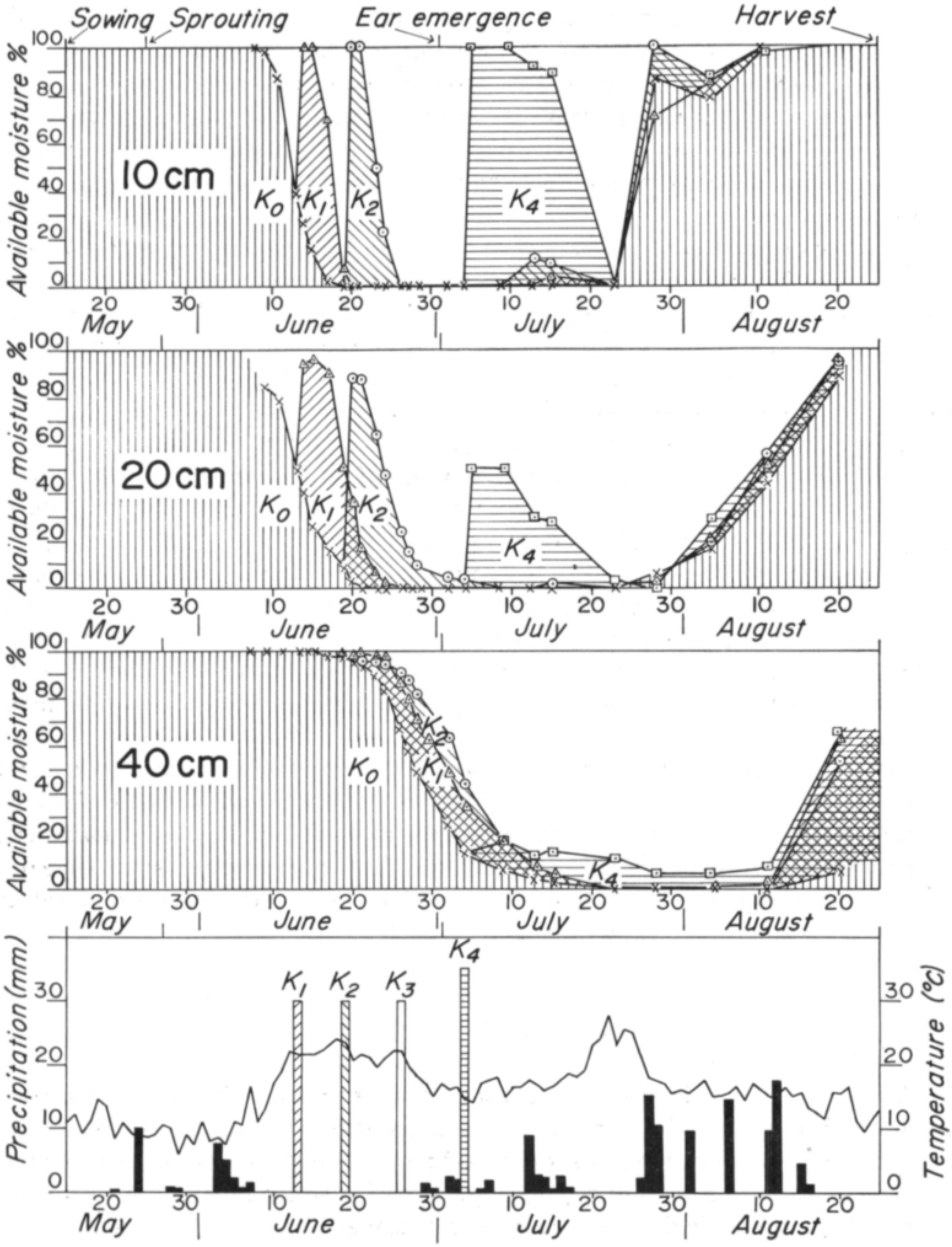

Figure 3. Effect of sprinkler irrigation and precipitation on the moisture conditions at various depths of the soil in 1966.

× ——— × = not irrigated (K_o)
△ ——— △ = 30 mm of irrigation on June 13 (K_1)
○ ——— ○ = 30 mm » » on June 19 (K_2)
□ ——— □ = 35 mm » » on July 4 (K_4)

spite of this, the effect of the sprinklings, also that of the fourth one, was detectable even at the depth of 40 cm 2 or 3 days after the irrigation. On the basis of the shape of the curves it may be concluded that a small part of the water applied has been percolated through the larger pores down to the depth of 40 cm. The profitable influence of irrigation down to the depth of 40 cm may be partly caused by the fact that the plants easily got water from the top soil and the water reserves in deeper layers were saved.

It is important to note the rapidity with which the irrigation water was taken up by plants. The influence of the first two applications of water, and very likely also that of the third one, disappeared within about one week from the soil. Consequently, the average rate of evapotranspiration was as much as 4 mm per day. It can also be seen from Figure 3 that the water was simultaneously consumed by plants from the whole root zone. The water uptake was, however, more effective in the upper layers of the soil, because the peaks of the courves corresponding to the depth of 10 cm tend to be narrower than those of 20 cm. The effect of the fourth irrigation on the soil lasted almost three weeks. This may be attributed to a change in the weather. In this period the days were cool, cloudy and also partly rainy.

It is interesting to observe also the influence of natural rains on the soil moisture conditions. At the end of July, during three days the total precipitation was 28 mm. The soil almost reached the field capacity at the depth of 10 cm, but at 20 cm the moisture remained at about the wilting point, and these rains had no effect on the depth of 40 cm.This will also prove that large amounts of water are needed for moistening a dry clay soil.

In August, also the deeper layers of soil were moistened by rains. The moistening was somewhat quicker in the plots irrigated than in those not irrigated. This may indicate that the soil moisture conditions on the plots irrigated had been maintained more profitable. This will hold true of the last irrigation carried out, while the earlier applications of water promoted ripening, and obviously therefore decreased the water demand of vegetation in August.

Discussion

The action of sprinklers (Figure 2) compared with Swedish investigations (HALLGREN and JOHANSSON 1958) appears to be fairly good. The area of the soil beside the sprinklers which got too wet is only 1—2 per cent of the area of the whole irrigation circle. A disadvantage of no great importance is also the fact that at the farthest distance from the sprinklers less than the average amounts of water were accumulated. In practice, in order to irrigate a soil thoroughly, the sprinkling circles must be intersected. The amount of water per the area which will be irrigated twice would thus raise too high, unless the distribution on the edges will be lower.

According to the present study, the sprinklers with two nozzles distributed water more uniformly than those equipped with one nozzle. Besides the uniformity of irrigation the sprinklers with two (or more) nozzles have another advantage too: By shutting the other nozzle it is possible to start the irrigation with a lower intensity, which is of importance on the soils slaking easily. After a cautious preliminary moistening the rate of irrigation can be raised by opening the closed nozzles.

The uniformity of irrigation depends also on different adjustments, among other things on the operating pressure and on the nozzle size. More attention had to be paid to these factors.

It was proved, by following the water conditions in soil during the growing seasons, that the water consumption by spring cereals is very high in June and July, even 4 mm per day. Results of the same order have also been obtained in Sweden (ANDERSSON 1961). Because the precipitation in that period was low, the natural water reserves were put to a severe test.

The influence of an irrigation of 30 to 37 mm disappeared from soil already in 1 to 2 weeks, so that one irrigation was not sufficient to ensure favourable water conditions to plants for the whole growing season. In 1966, according to Figure 3, all four applications of water making a total of 125 mm would have been required. Perhaps not even this high amount of water would have ensured the ideal water supply to the root zone.

Very large amounts of water are required for irrigating a dried clay soil if the whole root zone is wanted to be moistened to the field capacity, as it is recommended by some investigators (JOHANSSON 1959). An irrigation of 35 mm carried out on the 4th of July 1966, moistened the soil at the depth of 10 cm to field capacity, but at the depth of 20 cm only to 50 per cent of the available water capacity and at the depth of 40 cm the influence of the irrigation was low. Perhaps double amount of water, or 70 mm, would have been necessary for moistening the whole profile to the field capacity. Figure 3 also indicates that at the turn of July to August, when, obviously, transpiration was less than earlier in the summer, precipitation during 1 ½ weeks was 52 mm which had no effect on the soil moisture content at the depth of 40 cm. Only when an additional 30 mm of water was received (on August 11—12), or in total more than 80 mm, the soil began to get moist also in deeper layers.

It is also interesting to note that a part of both irrigation water and rain water percolated deeper before the upper layers of soil had time to reach the field capacity. This phenomenon will be, of course, the more distinct the better the permeability and the worse the capillarity are in a soil. Therefore, in a clay soil with a good permeability some of the irrigation water may be lost, if it is tried to moisten the whole root zone to the field capacity.

The most important result of this investigation is the observation that spring cereals in Finland may have a surprisingly serious shortage of water. This is not difficult to understand. It is true that the growing season in Finland is short, but the daytime is long and plenty of radiation energy is available. The precipitation is usually at its lowest when transpiration by spring cereals is the most effective.

The experimental years were drier than normal, which means that the need of additional water may not every year be as severe as during these growing seasons. On the other hand, even more serious lack of water may exist in many fields, which are more sensitive to drought than the experimental soils.

Summary

During the last three years, 1964—66, investigations on sprinkler irrigation of spring cereals have been carried out. The experimental fields were clay soils in Southern Finland. Neutral river and lake waters containing small amounts of soluble salts were applied in the nighttime. The application rate of the rotary sprinklers used was 2.5—4 mm per hour with the radius of 12 ± 2 m. With this technique the experimental soils having poor structure endured the irrigation without any crust formation.

It was found that the sprinklers equipped with two nozzles distributed the water more uniformly than those with one nozzle. With the former sprinklers a fairly good uniformity was attained: The amount of water usually varied between 25 and 35 mm with an average of 30 mm, except in a relatively small area nearest to the sprinklers which received too much water and in the area at the greatest distance from the sprinklers with less than the average amounts of water.

The soil water conditions were followed by gypsum blocks inserted at different depths. In each experimental year, within 2—3 weeks from sprouting, the available water in the top soils decreased to 50 per cent of the total capacity. This dry condition existed for two months in the years 1964 and 1966 and for one month in 1965. During these dry periods the top soils were near the wilting point for a long time, and in 1966 the available water was wholly exhausted. The influence of transpiration was effective also in deeper layers. In 1966, the soil reached the wilting point also at the depth of 40 cm and stayed at this condition for about one month.

The effect of a 30—37 mm irrigation on the soil moisture conditions lasted only for 1—2 weeks. Thus, the rate of evapotranspiration was as much as 4 mm per day. The plants consumed water simultaneously from the whole root zone, yet, most effectively from the surface layers.

The top soil (20 cm in thickness) which had reached the wilting point was not completely moistened by the amounts of water applied. This indicates the high capacity of clay soils to store water. It is also noteworthy that a part of irrigation water percolated to 40 cm before the soil at the depths of 10 and 20 cm had time to get to the field capacity.

In experimental years, to ensure favourable moisture conditions to spring cereals several high applications of water would have been needed. This proves that also during the short growing season in Finland a serious shortage of water may occur.

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SELOSTUS:

KEVÄTVILJOJEN SADETUKSESTA ETELÄ-SUOMEN SAVIMAILLA

I. Sadetustekniikasta ja sadetuksen vaikutuksesta maan kosteussuhteisiin

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Poutavuosina 1964—66 järjestettiin kevätviljojen sadetuskokeita hiesusavimailla Espoossa. Heikkorakenteiset maat säilyivät kuorettumatta, kun sadetukset suoritettiin yöaikaan hidassadettimilla tehon ollessa 2.5—4 mm tunnissa.

Sadetuksen tasaisuutta tutkittaessa päästiin melko hyvään tulokseen kahdella suuttimella varustetuilla ympyräsadettimilla, jotka jakoivat veden kahteen vastakkaiseen suuntaan vesisuihkun hajoittajan hajoittaessa vain toista suihkua.

Maan kosteussuhteita seuraamalla pääteltiin kevätviljojen kärsineen huomattavaa veden puutetta jokaisena koevuonna, vaikka maat eivät olleet erityisen poudanarkoja.

30—37 mm sadetus ei täysin riittänyt kostuttamaan lakastumisrajan saavuttanutta ruokamultakerrosta kenttäkapasiteettiin, mikä osoittaa savimaan suurta veden varastoimiskykyä. Sadetuksen vaikutus hävisi maasta 1—2 viikon kuluttua, joten haihtuminen oli jopa 4 mm vuorokaudessa. Suotuisten kosteusolojen turvaamiseksi koko kasvukauden aikana kevätviljoille olisi pitänyt antaa useita runsaita sadetuksia.