THE FUTURE OF SUBSURFACE IRRIGATION: A METHOD OF SAVING WATER

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Research with subsurface irrigation at New Mexico State University has been accomplished under a Water Resources Research Institute project in cooperation with the New Mexico Agricultural Experiment Station. The research has been conducted jointly by the Agronomy Department and the Agricultural Engineering Department. Dr. Boyce Williams of the Agronomy Department has been studying mainly the influence of subsurface irrigation on cotton yield and fiber quality, and I have been working mainly with the engineering aspects of design and management of the system, and consumptive use of water by cotton.

For three years cotton was grown on a field containing eight subsurface-irrigated plots which were interspaced with eight surface irrigated plots. All plots were 158 feet long and each plot contained half-inch perforated plastic pipe which was buried under each row to a depth of about 12 inches. These pipes were connected to a two-inch manifold header for each plot. A two-inch pipe with a meter was used to connect the headers to the main line of two-inch plastic pipe. The perforations in the half-inch pipe were 0.030 inch in diameter. They were made by a 0.030 drill in preference to a punch since previous tests in the laboratory showed that drilled holes produced more uniformity of flow.

The surface-irrigated plots were irrigated from alfalfa valves at the head of each plot. These valves received water from a 10-inch underground pipeline. Alfalfa valves were also installed for each subsurface-irrigated plot to permit surface irrigation and leaching in the event that salt accumulated in these plots. A salt buildup near the ground surface was considered possible due to evaporation of capillary water flowing upward from the perforated pipe.

During the first two years there was no appreciable buildup of salt in the soil. Measurements for the third year have not been completed to date.

Figure 1 which was taken from a magazine shows an artist's concept of what subsurface irrigation looks like. It shows water squirting out of all the little holes in the perforated pipe. Actually, the pipe buried in the ground has soil pressed up against the holes and as the water comes out it flows through the pores in the soil. The flow pattern is approximately spherical as shown by the circular lines in Figure 2 if flow rates from perforations are low and water moves

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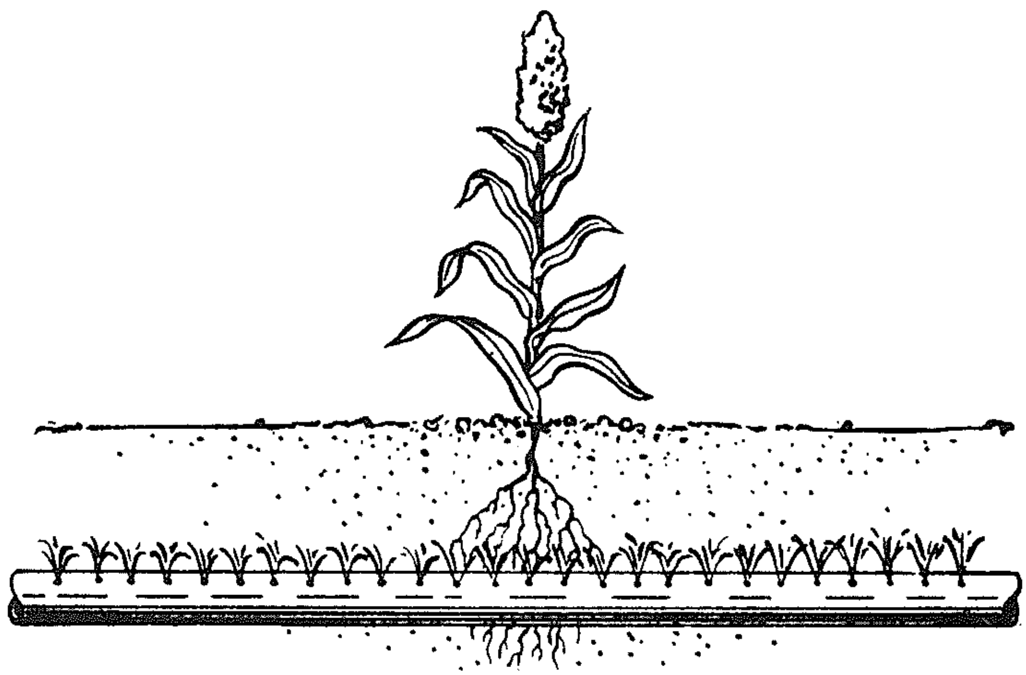

FIG. 1 ARTIST'S CONCEPT OF SUBSURFACE IRRIGATION.

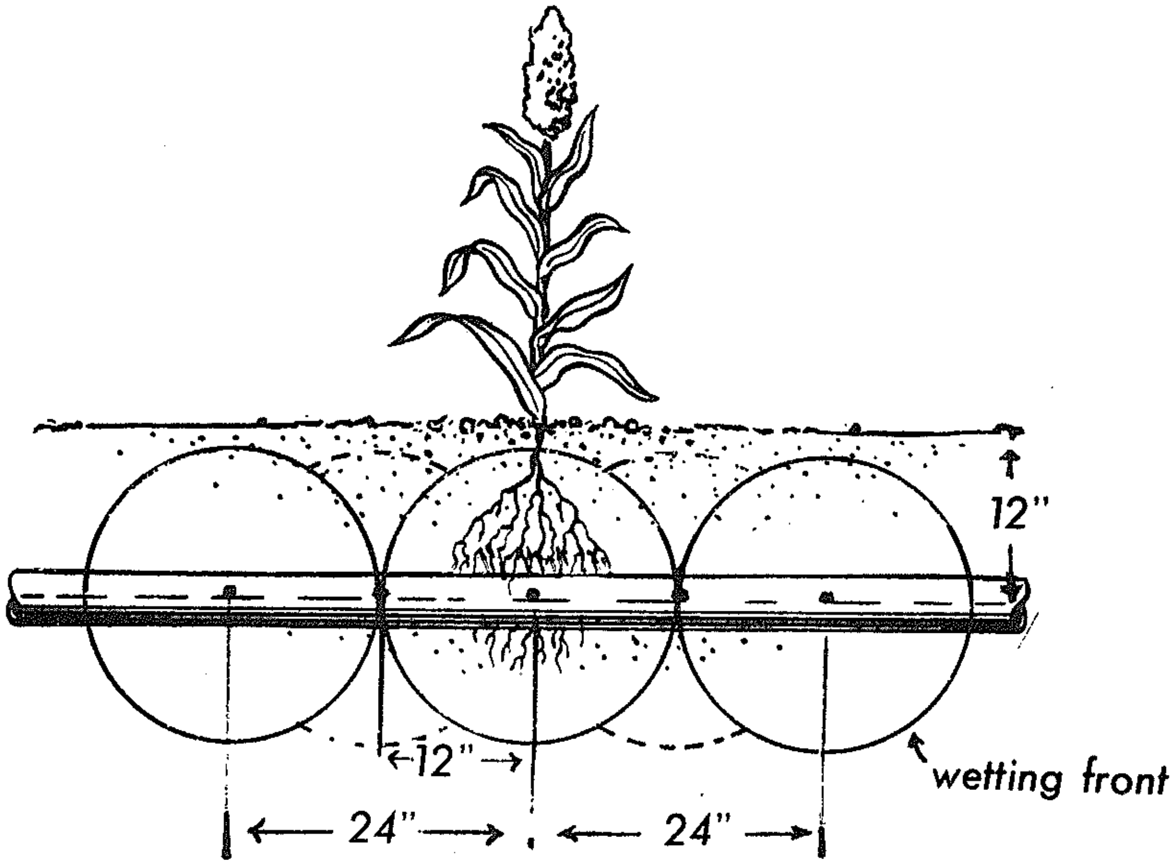

FIG. 2 WETTING FRONT OF SOIL MOISTURE MOVING BY CAPILLARY FLOW FROM PERFORATED PIPE.

through the soil by capillary flow. When flow rates through the perforations are in excess of the capillary flow capacity of the soil, the excess is pulled downward by gravity and may be lost below the root zone by deep percolation. To keep the soil surface as warm as possible at planting time and to minimize weed growth and salt accumulation at the surface it is desirable to keep the ground surface dry when irrigating with a subsurface irrigation system. With the perforations spaced 24 inches apart on a pipe placed 12 inches below the ground surface the moisture pattern would be somewhat as shown by the full circular lines in Figure 2 if capillary flow conditions prevail. There would be some unduly dry zones at the seed planting depth if the ground surface above each hole was kept dry. Because of this the spacing was reduced to 12 inches to provide more uniformity of wetting front at the planting depth near the ground surface as indicated by the broken circular lines in the figure.

This research was done on one of the slowest subbing soils in this area. In the area near Lubbock, Texas some subsurface systems have holes 40 inches apart and capillary movement appears to be satisfactory. However, that area is more humid and rains have helped to provide uniform moisture conditions near the soil surface at planting time. With the slow-subbing soil used in the local project, there have been problems of getting a complete and uniform stand on the subsurface plots each year. In order to have stands which were comparable to the uniform cotton stands on the surface-irrigated plots, surface irrigation water was applied to the subsurface plots to prevent skips. By putting some surface water on subsurface plots the differential between the treatments was somewhat reduced; but despite this, the yield for the first two years from subsurface-irrigated plots was significantly greater than that from the surface-irrigated plots. This third year it was decided to let the crop grow with the skips to see how the fields compared. The skips in the cotton on the subsurface plots are shown in Figure 3 and the cotton with complete stands on the surface irrigated plots is shown in Figure 4.

Each year the plants on the subsurface irrigated plots grew faster and the squares and boles developed earlier. This was particularly noticeable during the first year. By the time that the surface-irrigated plots had two squares the subsurface-irrigated plots had six squares. Table 1 shows cotton yields and inches of water applied for 1967 and 1968. The 1967 yields are also quite representative of the 1966 yields in that there was a significant increase in yield from subsurface-irrigation. The raw data for 1968 shows that 150 pounds more seed cotton was picked from the subsurface-irrigated plots despite the skips than was picked from the surface-irrigated plots. These data have not been analyzed for significance to date.

Measuring of water to the subsurface plots was accomplished by positive displacement meters on the lead-in pipe to the header of each plot. The meter is the type that is commonly used by cities to measure water to homes. Periodic tests have shown that these test meters have an error of

Fig 3. Cotton stand with skips on subsurface irrigated plot. July 24, 1968

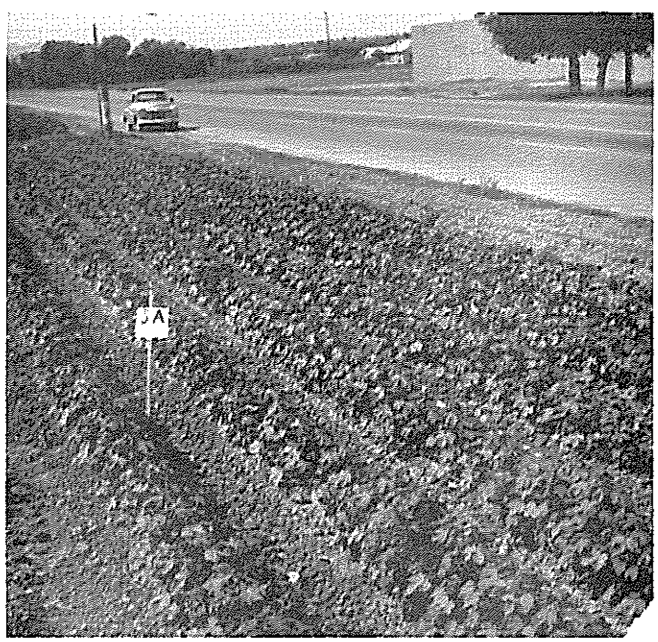

Fig. 4 Cotton stand with no skips on surface irrigated plot. July 24, 1968

TABLE 1. COTTON YIELDS AND IRRIGATION WATER APPLIED TO SURFACE AND SUBSURFACE PLOTS DURING 1967 AND 1968

1967 Treatments

	Surface Irrigation		Subsurface Irrigation	
	Heavy	Light	Heavy	Light
Water applied, inches	33.7	28.7	33.2	29.6
Seed cotton, lbs/acre	3337 bc	3272 c	3906 a	3409 b 1/

1968 Treatments

	Surface Irrigation		Subsurface Irrigation	
	Heavy	Light	Heavy	Light
Water applied, inches	27.6	23.4	21.9	18.8
Seed cotton, lbs/acre	3339 2/		3494 2/	

1/ Treatments not followed by the same letter are significantly different at the five percent level of probability.

2/ Average yields by irrigation method. Data have not been analyzed by Heavy and Light treatments to date.

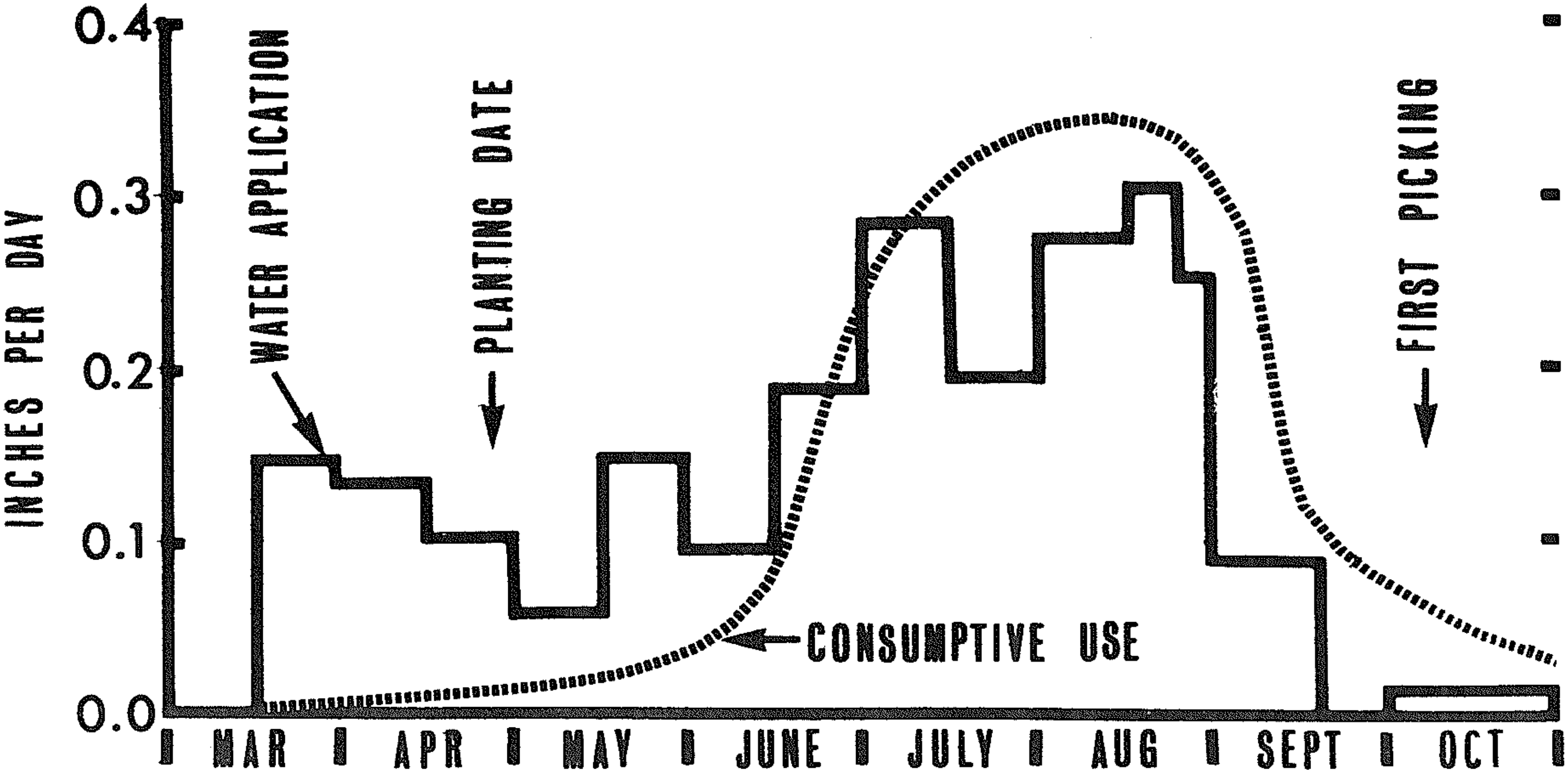

FIG. 5, CONSUMPTIVE USE BY COTTON AND RATES OF WATER APPLICATION INCLUDING PRECIPITATION, 1968 (SUBSURFACE, HEAVY TREATMENT)

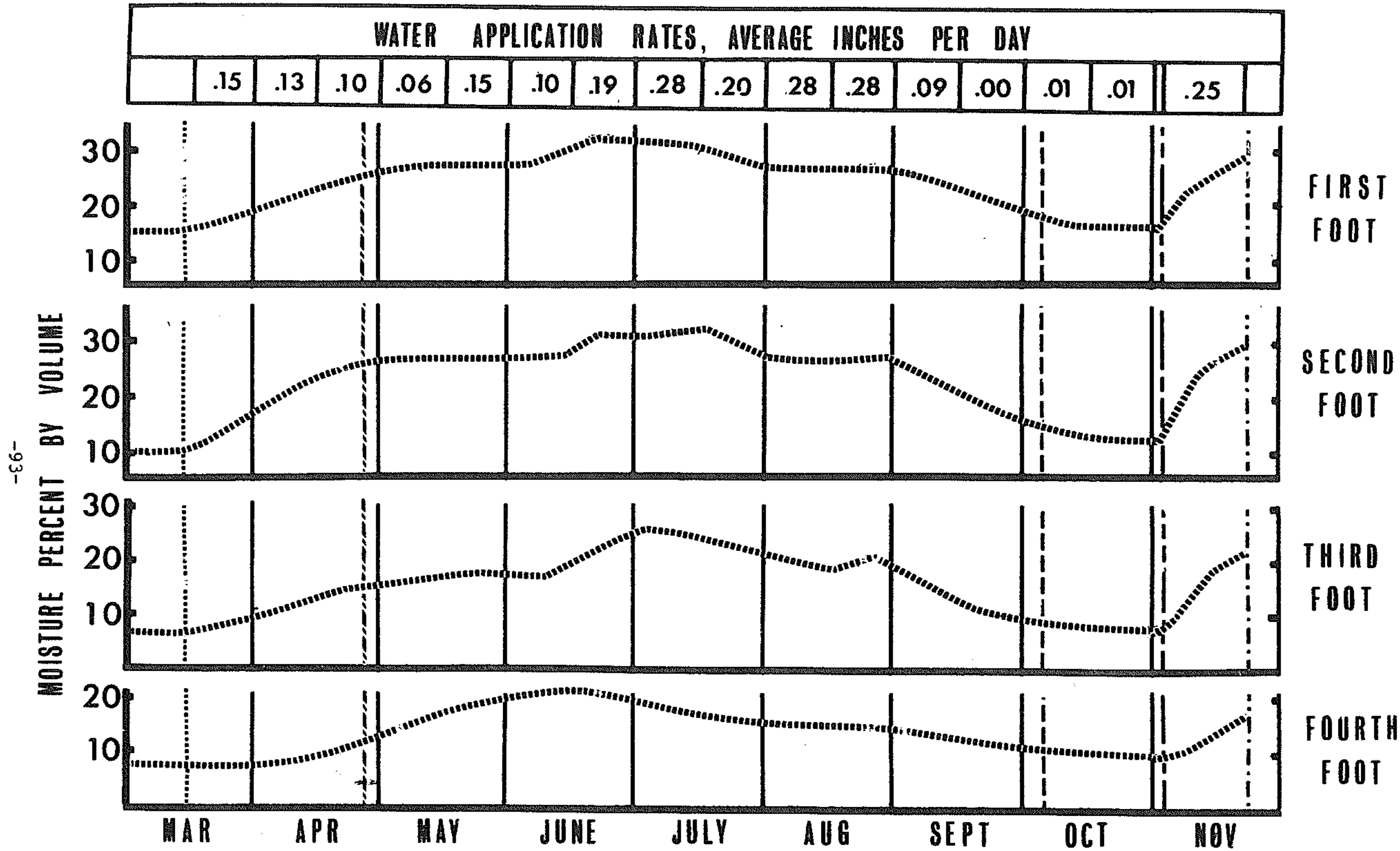

FIG. 6. SOIL MOISTURE VARIATION UNDER SUBSURFACE IRRIGATED COTTON, 1968

LEGEND: IRRIGATION STARTED .... PLANTING DATE –·–·–
FIRST PICKING — — —
LAST PICKING –·–·–
PRACTICE IRRIGATION — —

less than two percent. A Sparling meter in the 10-inch underground line was used to measure the water on the surface plots. The moisture levels in the soil were measured throughout the season with a neutron probe.

Dr. Williams will probably describe the fertilizer and irrigation treatments later, but I will briefly preview two irrigation treatments which are the "Light" Treatment and the "Heavy" Treatment. The plots designated for the light treatment had water applied in quantity sufficient to satisfy consumptive use. The plots designated for the heavy treatment received 25 percent more water than the place with the light treatment. See Table 1.

Figure 5 shows application rates to the subsurface plots in comparison to consumptive use. The preplanting irrigation commenced on March 15, about five weeks before planting. Water was applied at approximately 0.15 inches per day at the beginning of the season. The low application rate was selected to allow time for the water to sub up to the planting depth without having excessive deep percolation losses. A time clock was used to operate the pump for the subsurface system. Subsurface irrigation water was applied to the soil with the system operating 15 minutes during each hour or two throughout the day and night. The rate of flow was adjusted as needed during the season.

Figure 6 shows typical soil moisture levels in the upper four feet of soil in the subsurface irrigated plots throughout the 1968 irrigation season. Since water was being lost below the upper foot soon after March 15 as shown by the rise in the curves below the first foot, the application rates were reduced during April and early May to minimize deep percolation losses. The slow drainage downward continued until the consumptive use rate increased in June sufficiently to use the water as it was applied. Application rates shown in Figure 5 were maintained early in the season at rates higher than consumptive use until the latter part of June to assure that adequate moisture would be available in the upper foot while the small plants were extending their roots and becoming well established. After July 1 the application rate was held slightly below the consumptive use rate to permit the plants to draw slightly on stored soil moisture. Since the July - August period is the major time of fruiting, moisture levels were held high during these months. Only a slight lowering of moisture levels was permitted during August.

Figure 7 shows how soil moisture levels varied with surface irrigation during 1968. The solid black vertical lines represent dates of irrigation. Immediately before each irrigation the moisture level was low. The difference in moisture levels before and after irrigations represents the quantity of moisture stored in the soil during irrigations, and the difference in moisture levels between irrigations represents the quantity of moisture depleted.

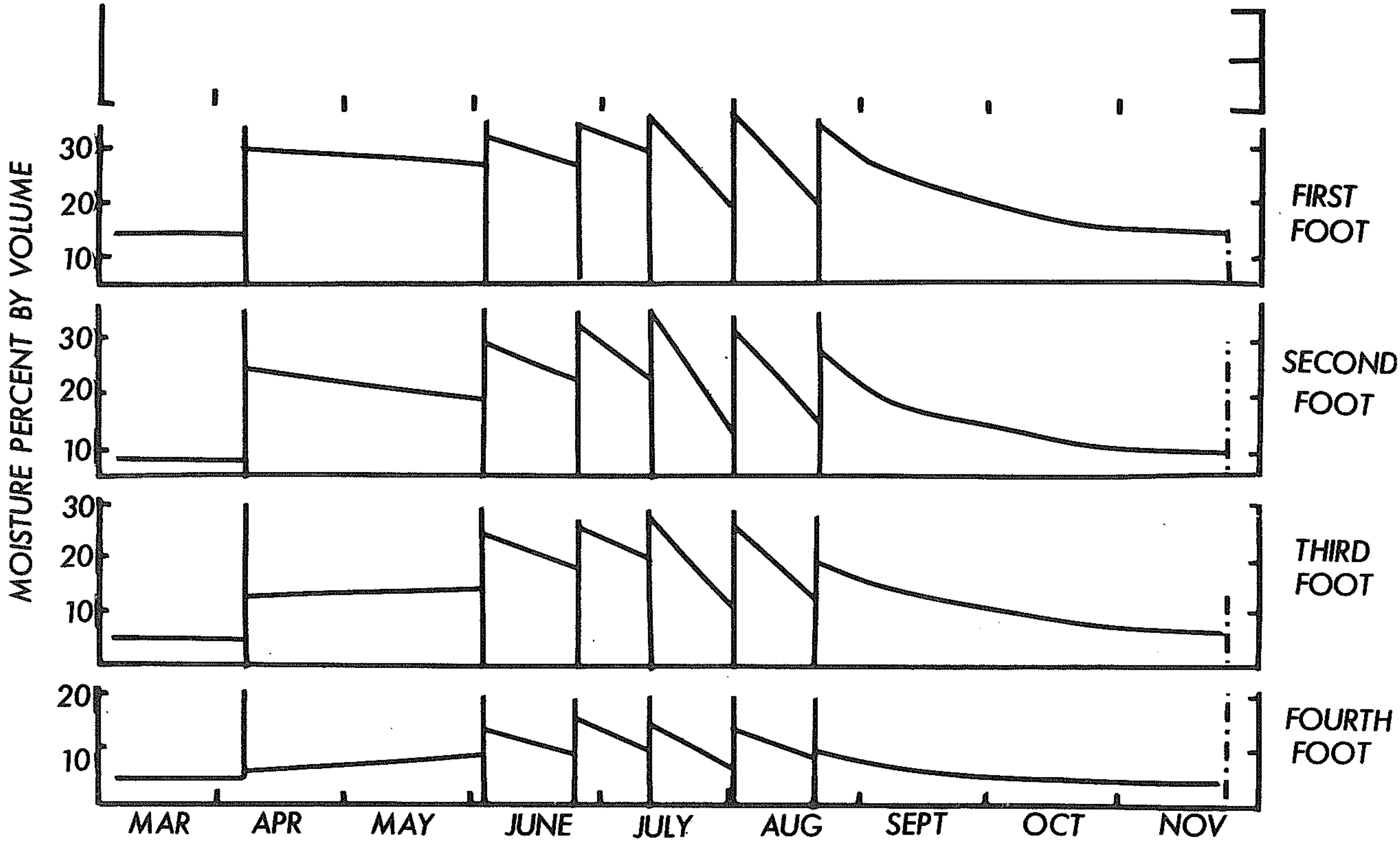

FIG. 7. SOIL MOISTURE VARIATION UNDER SURFACE IRRIGATED COTTON, 1968

Yesterday Governor Bolack mentioned that he learned from his research work that it was better to irrigate with one-half as much twice as often. One of the reasons for this is the up and down variation of the moisture percentage in the soil with ordinary surface irrigation. As the moisture level lowers between irrigations the soil moisture tension increases and more energy must be expended to remove the moisture from the soil. This condition is usually more pronounced in the upper part of the root zone where there are more roots, more organic matter and fertilizer and better aeration. These and other factors cause moisture depletion to be greater in the upper part of the root zone. Therefore a continuous supply of available moisture in the upper and most import part of the root zone is essential for high yield for most crops. By increasing the frequency of irrigations and applying less water each time, a buildup of soil moisture tension in the upper part of the root zone may be minimized.

When plants are wilting severely before an irrigation there is usually an ample supply of available moisture in the lower half of the root zone. Since the root growth in this zone is relatively sparse, the moisture cannot be moved sufficiently fast from the soil to the plant to retain plant turgidity. Moisture in the lower part of the root zone has some benefits to crop yield and will keep the plant from dying but it is not as effective for high crop production as the available moisture in the upper part of the root zone.

Subsurface irrigation as used in the project is somewhat of an extension of Governor Bolack's statement - "irrigate with half as much, twice as often." The subsurface plots have been irrigated a hundred times more often with less than one-hundredth as much each irrigation. These plots have had very light irrigations every hour or two, day and night.

Subsurface irrigation practices in the project have prevented almost completely up and down fluctuations of soil moisture as shown in Figure 6 during the months of June, July and August, when the consumptive use of water by the crop is the greatest.

Subsurface irrigation has other benefits besides those which have been presented. Weed growth on subsurface-irrigated plots has been considerably less than that on the surface irrigated plots. Subsurface irrigation also lends itself to automation. With the development of ways to make perforations or slits in pipe or other orifices with which clogging may be minimized, farmers will be able to irrigate extensive acreages by automatic controls at the pump. Sensors in the soil to measure tension may be used to turn the pumps on and off to maintain optimum moisture conditions.

Subsurface irrigation systems may be designed to apply water efficiently and place the water when and where it will be best utilized. The peak consumptive use rate for most crops in this area ranges from 0.30 to 0.40 acre-inches per acre per day. This represents slightly less than seven gallons per minute of water per acre. With subsurface pipes under rows 1000 feet long there would be approximately 13 lines per acre if rows are spaced at 38 inches. With continuous flow to satisfy consumptive use each line would carry seven-thirteenths of a gallon per minute with a pressure head loss of less than two feet of water. By using ori ices with an appropriate size to have the subsurface lines operate with 20 feet of head at the upper end and about 18 feet at the lower end, there would only be about five percent difference in the rates of discharge in the soil at the extreme ends. By using smaller pipe orifices and higher operating pressure heads the water application efficiency could be even higher than 95 percent.

During three years of operation of the subsurface irrigation system the operating pressure has gradually built up from five feet to slightly more than 14 feet of water. The increase has been unimportant with respect to the amount of pressure, but it is important in that it represents clogging in the perforations. Samples of pipe removed from the field have shown that about two holes in sixteen have become completely clogged and some of the remaining holes have been partially clogged. It is unlikely that these systems could be installed to operate for 10 to 20 years without unusual filtering requirements. In recent research by Davis in California with subsurface irrigation of potatoes, machinery has been developed with which half-inch plastic pipe can be planted and harvested with the potatoes. Under this practice the perforated pipe could be cleaned each fall for use during the next season.

POTENTIALS OF SUBSURFACE IRRIGATION

In the opinion of the leaders in this project subsurface irrigation has more potential for automated and efficient application of irrigation water than any other irrigation system now operable (7). The appended references represent recent and current research work which increases confidence that solutions will be found for the problems that have been holding back subsurface irrigation.

Subsurface irrigation opens the door for a new means of applying fertilizer, fungicide, pesticide, and air directly in the root zone. No other system offers such potential as a means for balancing plant growth factors. It is easy to envision benefits from pumping air through the system into the root zone during periods of extended rainfall or flooding which ordinarily may damage crop production by preventing adequate aeration.

With continued research on filters and on the development of slits (2), orifices, or other openings which will minimize clogging or which will be self-cleansing under intermittent application of extra water pressure, it is expected that subsurface irrigation will become one of the most important methods of automated irrigation in the future.

SUMMARY

Yields from cotton grown with subsurface irrigation were significantly greater than yields obtained with surface irrigation. Potential water savings with subsurface irrigation as compared to surface irrigation appear to be in excess of 30 percent. Difficulty was experienced in obtaining a complete stand of cotton due to slow rate of capillary flow from the subsurface perforated pipe to the shallow planting depth. The subsurface irrigation system consisted of perforated half-inch plastic pipe which was placed 10 to 12 inches deep under each row. Suspended particles in filtered water partially obstructed the flow from the pipes to the soil and required an increase in pressure head to apply design rates of flow through the system. Water application rates with the subsurface irrigation system ranged mainly between 0.10 and 0.30 inches per day. Water was measured with positive displacement meters and application was programmed with a time clock.

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