# SPRINKLER LEACHING PROGRAM

# FOR VERY SALINE VIRGIN DESERT SOILS IN THE

# LA JOYA IRRIGATION PROJECT

# PERU

by

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In cooperation with
USAID/Peru

and

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Dirección de Preservación y Conservación
Dirección General de Aguas

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# PURPOSE

This report is a result of an official request from the Peruvian Government through USAID/Peru and AID/Washington (Task Order N°527-11-110-060, Basic Agreement N°AID/csd-3703) to Utah State University for Technical Assistance. The following statement of work was defined:

"The A.I.D. Mission in Peru has agreed, in accordance with Project Agreement 21, to provide for technical assistance to the Ministry of Agriculture (MOA) in the solution of specific problem areas considered to be of high priority to the Government of Peru.

"One of these priority areas pertain to the development of a Pilot Overhead Sprinkler Irrigation Project in the valley of La Joya with an investment of thirty million dollars to provide water to some 1400 hectares of land. The first stage of this project is to leach the salt deposits from the soil profiles of this arid region, utilizing the sprinkler irrigation system.

"In pursuit of this objective the Contractor (Utah State University) agrees to provide one Advisor, at the Ph.D. level, to serve as a specialist in Agricultural Engineering and Irrigation, to assist the Irrigation System Division of the MOA in a series of studies related to the leaching of salt deposits in soils.

"Specifically the Advisor will review soil maps, topographic information and the results of laboratory and site research particularly related to the San Camilo Project. As a result of this evaluation the Advisor will prepare a program for salinity control using the sprinkler irrigation method. The program will be designed to remove deposits

from deep soil zones without affecting the growth of the roots in the plants being cultivated using the least amount of water possible in the leaching process. The Advisor will also provide such additional technical and professional assistance as may be agreed to, as necessary, between the Contractor and the Ministry of Agriculture and/or the A.I.D. Mission in Peru."

Term of Performance

"The Contractor shall perform the technical services described above during the period April 8 through July 7, 1974, approximately."

## ACKNOWLEDGEMENTS

The writer wants especially to recognize the interest in solving the agricultural development problems in Peru held by Dr. Arturo Cornejo T., Director General de Aguas, and by Ing. Julio Lostao E., Director de Preservación y Conservación (DIPRECO) of the Ministry of Agriculture. Without their support, this study would not have been undertaken.

Praise must also be extended to Ing. Enrique Franco M., Sub-Director de Rehabilitación de Tierras (SUDRET), whose dynamism and dedication to his work enabled the study to progress. Without his full-hearted cooperation very little would have been accomplished.

Recognition must also be given to Ing. Agr. Luis Manrique C. (SUDRET), who as the writer's counterpart, spent many days traveling in the field and working with the writer pursuant to the development of the study program.

No field evaluation would be forthcoming without the support of Ing. Roberto Rondón R., Chief, La Joya Project, who placed the personnel and facilities of the project at the disposal of the study. Special thanks must be extended to Ing. Agr. Sergio Pomé (La Joya Project) and Ing. Manuel Guzmán, Technical Assistant, (SUDRET), who were physically on the job supervising the field work in La Joya.

None of this would have transpired without the full cooperation of Dr. Curry C. Brookshier, Food and Agricultural Officer, USAID/Peru, who acted as intermediary to bring all interested parties together. Also, without the complete disposal to the writer's needs of office space and secretarial personnel, this report could never have been prepared on time. Miss Hilda Cobián and Miss Martha Ganoza (Support Services Contract) were particularly diligent in their efforts of typing and translating this report.

## PERSONNEL

A. TDY from Utah State University through the Bureau for Latin America, AID/W:

Dr. Edwin C. Olsen, Dept. of
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B. Peruvian counterpart from the Dirección General de Aguas, Sub-Dirección de Rehabilitación de Tierras (SUDRET), Ministerio de Agricultura.

Ing. Agr. Luis Manrique C., Jefe,
División de Recuperación del
SUDRET.

## ITINERARY

| | |
|---|---|
| April 15, 1974 | |
| 22.45 hrs | Arrival of Dr. Olsen in Peru. |
| April 16-17 | Studied information available on the La Joya Project in Lima. |
| April 18-20 | Visited the La Joya Project in Arequipa to see first hand what the situation was like. Also, journeyed to see the La Boya Project in Camaná. |
| April 22-25 | Stayed in Lima reviewing data and studies pertinent to the leaching problem in La Joya. Formulated preliminary leaching plan. |
| April 26-May 2 | Traveled to the North of Peru with the inspection tour arranged for the students attending the IV Curso de Drenaje de Tierras Agrícolas-Latinoamericano. Projects were visited in the Chiclayo, Piura and San Lorenzo areas. |
| May 3-7 | Began organizing the background material for final report in Lima. |
| May 8-11 | Traveled to Arequipa to set up sprinkler leaching experiment. Selected site and explained the work plan to personnel in |

the project. Pressurized water system for the sprinklers was not ready, so a pump was available to take water out of a nearby surface canal. The pump was too small. Pressurized water supply was to be ready in ten days time.

May 13-17 — Traveled to Chiclayo and Piura to observe and discuss problems arising in the Chacupe and Curván pilot drainage studies.

May 18-June 10 — Prepared report containing the leaching program for the Moro-Moro soils in the La Joya Project, Arequipa. The English version was completed and the Spanish translation was begun.

Several communications were made with the project personnel in Arequipa, but the water supply was still not ready. It was, therefore, not yet possible to set up a leaching field trial using the sprinkler irrigation system.

Consumptive use requirements were estimated for the pilot study area in Chacupe. It seemed from the visit there on May 13 that the field personnel were under-irrigating their sorghum field test. The consumptive use estimates confirmed this.

A program of irrigation was developed which would apply adequate water to meet both the consumptive use and leaching requirements for sorghum in the Chacupe area.

| | |
|---|---|
| June 11-12 | Visited the experimental station which serves the central mountain area of Peru at Huancayo. The director reported that little use is made of the irrigation system in the Mantaro Valley because of contamination from the mines in the headwaters of the Río Mantaro. The Director was anxious to investigate this problem in order to promote the planting of wheat during the winter months of low rainfall. |
| June 13-30 | Finished the Spanish version of the leaching program for Arequipa. An oral presentation was made to the personnel of DIPRECO on June 20.<br>The planned leaching program was also presented at the first national Convention of Agricultural Engineers in Lima, June 25-28. |
| July 1-3 | Visited some coastal irrigated valleys to the north of Lima as far as Chimbote with |

the AID Food and Agriculture Officer to determine what development problems are being encountered in those areas.

July 4-10 Finalized the report on the salt problem in La Joya and distributed it to the appropriate agencies.

# LA JOYA PROJECT

## Location

The La Joya Project area is located in the Department of Arequipa in the southern part of Peru at about 16° South Latitude, 72° West Longitude, and at an elevation of about 4100 ft (1,250 m). The Pan American highway, connecting Lima to the north with Tacna in the south near the Chilean border, passes through the project area at about 1000 Km from Lima. The city of Arequipa is about 60 Km to the east of the project area on a branch of the Pan American Highway.

## Background

Irrigation began in the year 1939 in the Pampa de La Joya on about 3800 ha in an area that is now referred to as "La Joya Antigua". Water was diverted from the Río Chili and distributed by a system of canals and ditches.

The construction of two storage reservoirs in the high mountain area of the Department of Arequipa permitted the expansion of the irrigated area in La Joya in what is referred to as the San Isidro sector. San Isidro is composed of two settlements. Settlement N°1 comprising 1041 ha was initiated in 1966 and settlement N°2 having 643 ha in 1969. In the San Isidro sector as well as in La Joya Antigua, surface irrigation was practiced with a resulting high water use because of the extremely sandy soils found in the area.

The construction of a third storage reservoir in 1971 makes available sufficient water for about a total of 7600 ha to be irrigated

in the Pampa de La Joya. About 2100 ha of new land will be developed in eight additional settlements. One settlement will be inaugurated in the San Isidro sector, one in San José, and six settlements are planned in a block which will comprise the San Camilo sector.

Because of the excessive use of water which results from surface methods of irrigation on sandy soils, the eight new settlements have been planned and designed for sprinkler irrigation. There is sufficient difference in elevation between the main diversion canal and the lands to be irrigated to obtain adequate pressure in a pressurized network of pipes for the sprinklers to operate without pumping. The pipe distribution system for some of the settlement areas in the San Camilo sector is nearly ready to deliver water. As of the day of this writing, no water has been applied to the lands in the new settlement areas.

## Climate

A meteorological station was established in San Isidro sector in 1965. Temperature and relative humidity are available from October 1965 and evaporation from a Class A Pan from February 1970. The station (M.A.P. 804) is located at Lat. 16° 44' S and Long. 71°52' W at an elevation of 1255 meters above mean sea level.

The mean annual temperature is reported to be 18.9°C with a mean annual maximum of 27.3°C and a mean annual minimum of 10.5°C. The hottest month is February and the coldest is June.

The mean annual relative humidity is 53 percent varying from a mean maximum of 66 percent in February and March to a mean minimum of 43 percent in July.

Pan evaporation totals about 2000 mm annually. It varies from a mean monthly low of about 114 mm in June to almost 200 mm in October and November.

No rainfall has been recorded in the project area.

The mean monthly data as reported by Pinto (1972) for the period ending in May 1972 are given in Table 1.

Topography

The terrain has an inclination of a uniform slope of about 2.5 percent in the East-West direction. The difference in level between the highest and lowest part of the area is about 175 meters (1355 m as a maximum and 1180 m above mean sea level as a minimum).

Soils

The soils throughout the project area are extremely sandy. The average composition of the top 1.5 meters is about 82 percent sand, 15 percent silt, and 3 percent clay. The texture is classified as loamy sand to sand. The surface layer generally has more silt than is found deeper in the profile. Five soil series have been described in the area: San Camilo, San José, Moro-Moro, La Joya and Flavio. The first two series, San Camilo and San José, are of alluvial origin. Representative profiles of each soil series are given in Figure 1.

The series San Camilo and San José generally are non-saline, non-sodic soils. From the salt-sodium viewpoint they present no problem. The Moro-Moro series is very saline in general, and has discontinuous small lenses of cemented layers or crusts at varying depths in the

Table 1. - Mean Monthly Climatological Data for the San Isidro Station through May 1972.+

(Latitude: 16°44' S, Longitude: 71°52' W, Elevation: 1255 meters)

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature, °C | 19.9 | 20.1 | 19.6 | 18.6 | 17.7 | 15.7 | 16.4 | 16.4 | 17.4 | 18.2 | 18.3 | 19.0 | 18.1 |
| Relative Humidity, % | 63 | 66 | 66 | 60 | 50 | 50 | 43 | 45 | 47 | 44 | 49 | 56 | 53 |
| Precipitation, mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Evaporation, mm | 186.0 | 165.2 | 170.5 | 150.0 | 148.8 | 114.0 | 148.8 | 155.0 | 159.0 | 195.3 | 198.0 | 182.9 | 1973.5 |

+* Temperature and relative humidity measurements were begun in October 1965 and evaporation in February 1970.

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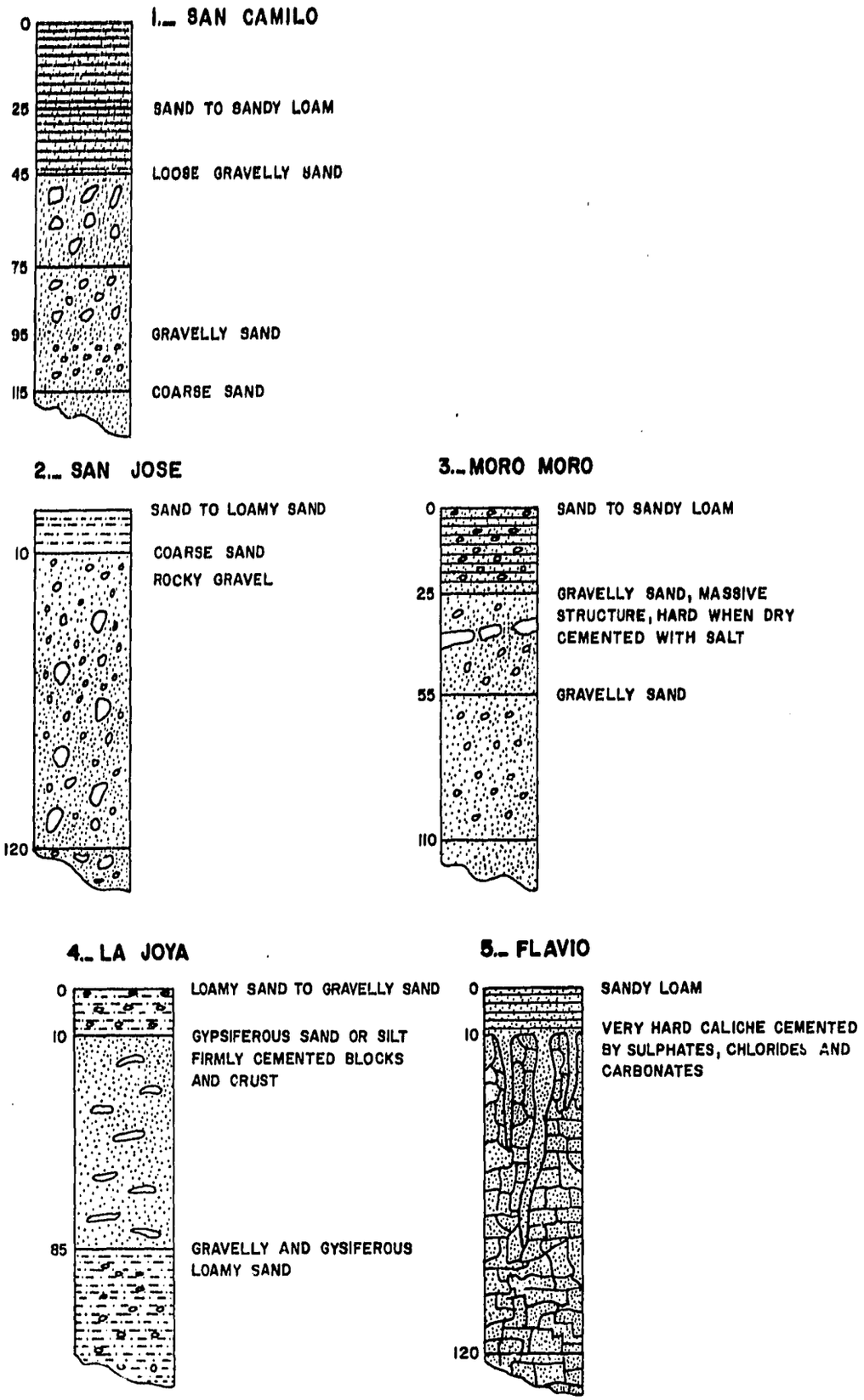


Fig 1.- REPRESENTATIVE PROFILES OF THE SOIL SERIES IN THE LA JOYA PROJECT

profile. These crusts are generally found between 20 cm and 80 cm depth, and vary in thickness from less than 1 cm to 10 cm or more. The thicker crusts are extremely hard and have the appearance of sandstone. The cementing agent of this material is extremely saline, and composed mostly of sodium chloride. When water is applied to the crusts, they soften and dissolve rapidly. The electrical conductivity of these soils is variable, but it is always greater than 100 mmhos/cm at 25°C in the saturation extract with a maximum of 400 mmhos/cm. At the same time the exchangeable sodium percentage on the soil complex is generally low, permitting the Moro-Moro Soil Series to be classified as saline-non sodic.

The La Joya series is similar to the Moro-Moro in that it has saline lenses and crusts, but it usually has lower electrical conductivities. It contains more gypsum than the Moro-Moro series and much of the crusting is composed of hard gypsum layers. The gypsum dissolves more slowly than the sodium chloride layers in the Moro-Moro soil series, but no problem is foreseen in the conversion of the La Joya soils into good agricultural soils.

The Flavio soil series has a very thin layer of topsoil underlain by a very hard sub-soil formed of conglomerate cemented by sulphates and chlorides. These soils are not considered to be arable and are not included within the area to be developed in the project.

The Moro-Moro soil series will be the objective of this evaluation.

## Water

The CENDRET (Centro de Drenaje y Recuperación de Tierras) laboratory made the analyses given in Table 2 for the San Isidro Canal in the La Joya project in 1972.

TABLE 2.- Water Analyses - San Isidro Canal

La Joya Project - 1972

| | Sample 1 | Sample 2 | Sample 3 | Average |
|---|---|---|---|---|
| E/C/ mmhos/cm | 0.84 | 0.80 | 0.80 | 0.81 |
| pH | 7.8 | 7.5 | 7.9 | 7.7 |
| $Ca^{++}$ meq/1 | 1.5 | 1.6 | 1.7 | 1.6 |
| $Mg^{++}$ meq/1 | 1.2 | 2.4 | 2.3 | 2.0 |
| $Na^{+}$ meq/1 | 3.3 | 3.8 | 3.7 | 3.6 |
| $K^{+}$ meq/1 | 0.4 | 0.3 | 0.3 | 0.3 |
| TOTAL CATIONS | 6.4 | 8.1 | 8.0 | 7.5 |
| | | | | |
| $Cl^{-}$ meq/1 | 2.1 | 2.3 | 2.4 | 2.3 |
| $SO_4^{--}$ meq/1 | 0.8 | 2.6 | 2.5 | 2.0 |
| $CO_3^{--}$ meq/1 | 1.2 | 1.4 | 1.4 | 1.3 |
| $HCO_3^{-}$ meq/1 | 2.2 | 1.9 | 2.0 | 2.0 |
| TOTAL ANIONS | 6.3 | 8.2 | 7.9 | 7.6 |

According to the U.S. Salinity Laboratory classification (1954), this water is a $C_3S_1$ water. Using the classification presented by Christiansen and Olsen (1973), the water would be Class 1 on the basis of SAR, RSC and chlorides; and Class 2 on the basis of Electrical Conductivity, Sodium Percentage and the Effective Salinity. (No data were available on the boron content). Overall, Christiansen and Olsen would give a classification of 2 to the water. No degrading effects should arise from good use and management of this water.

## Irrigation System

The new areas under development in the La Joya Project will utilize sprinkler irrigation. Water will be available at each farm unit from a buried mainline pressurized by gravity from the higher open canal. The initial design required a 12 m x 12 m sprinkler spacing using 5 mm diameter nozzles operating at 2.5 atmospheres pressure. This combination gave an average application rate of 10 mm per hour. The design has been changed to an 18 m x 12 m spacing with the other factors remaining as initially planned. This in effect reduces the average application rate to 6.6 mm per hour. One 3 in aluminum sprinkler lateral will be available to irrigate each 200 m x 250 m (5 ha) plot. (Oficina de Apoyo Técnico Proyecto La Joya - 1973).

## Previous Studies

According to Zavaleta (1969), most soils of the Peruvian coastal valleys have a high gypsum content and though some "have a high exchangeable sodium percentage in the soil complex, (15-60%), morphologically and physically they are not sodic soils. There is no sodium carbonate salinity." He concludes that leaching and drainage operations are sufficient for soil reclamation.

Velazco (1971) made a study of the leaching requirement for soils in the Majes Pampa, an area very near to and similar to the La Joya Project Area. He found, using intermittent ponding of successive 10 cm depths of water, that a depth of leaching water about equal to the depth of soil to be leached was necessary to reduce the electrical conductivity from initial values of 15 to 100 mmhos/cm to a final value of about 4.0 mmhos/cm.

Manrique (1974) made a mathematical analysis of the leaching requirements for the Moro-Moro soils in the La Joya Project. He used two hypothetical soil profiles, one having a saline - crust at the 30-40 cm depth and the other having two saline - crusts at 25-30 cm and 35-40 cm depths. On each profile he assumed two different combinations of leaching efficiency. His computations indicate that by applying water in daily 10 cm increments, a depth of leaching water equal to the soil depth to be leached is sufficient regardless of the leaching efficiency assumed and regardless of the number of saline crusts assumed. He concluded that 600 mm of leaching water would be sufficient to reclaim adequately the saline soils encountered in La Joya if no saline crusts were present. For soils having two or more crusts in addition to having an overall salinity, 1000 mm would be adequate to leach the soil to a depth of one meter.

Manrique, Guzmán, and Pomé (1974) conducted a leaching experiment on the Moro-Moro soil in La Joya. An area was selected having hard saline crusts in the soil profile. They used a block of 18 basins each 3m x 3m in size and having borders of 40 cm height. Water was applied by flooding to each basin in daily depths of 10, 20, and 30 cm with six replications for each depth. Preliminary results indicate that the conclusions obtained by Manrique from his mathematical model are reasonable.

Keller and Alfaro (1965) found that the leaching efficiency is improved as the application rate under continuous sprinkling decreases. The slower movement of water at the lower levels of saturation achieved by sprinkling resulted in significantly higher leaching efficiencies than could be attained by continuous ponding. Even at the highest rates used in their study, they found that 90 percent of the chlorides had been

leached from the soil when a ddpth of water equal to about 0.2 depth of soil to be leached had passed through the soil.

Leaching Procedure

A site will be selected in an area having the Moro-Moro soil class and to which sufficient water will be available to operate the sprinkler system at design capacity. A plot having the dimensions of 72 m x 200 m will be staked out as shown in Figure 2. This size allows for six positions of the sprinkler line.

Fourteen pits are to be dug to a depth of two meters in the locations shown in Figure 2. A soil profile description will be made for the full depth of each pit to verify that the test is located in the soil series Moro-Moro. Soil samples will be taken from each pit at 20 cm increments to a depth of one meter. The electrical conductivities of the saturation extract and a 1:1 extract are to be determined for each individual soil sample. The saturation percentage will also be determined on each sample. These analyses will establish the degree of initial salinity, and permit a correlation between the two extract dilutions. After each 25 cm of leaching water has been applied, additional soil samples will be taken from the same approximate positions and at the same depth increments. The electrical conductivities of only the 1:1 extract will be determined on these subsequent samples.

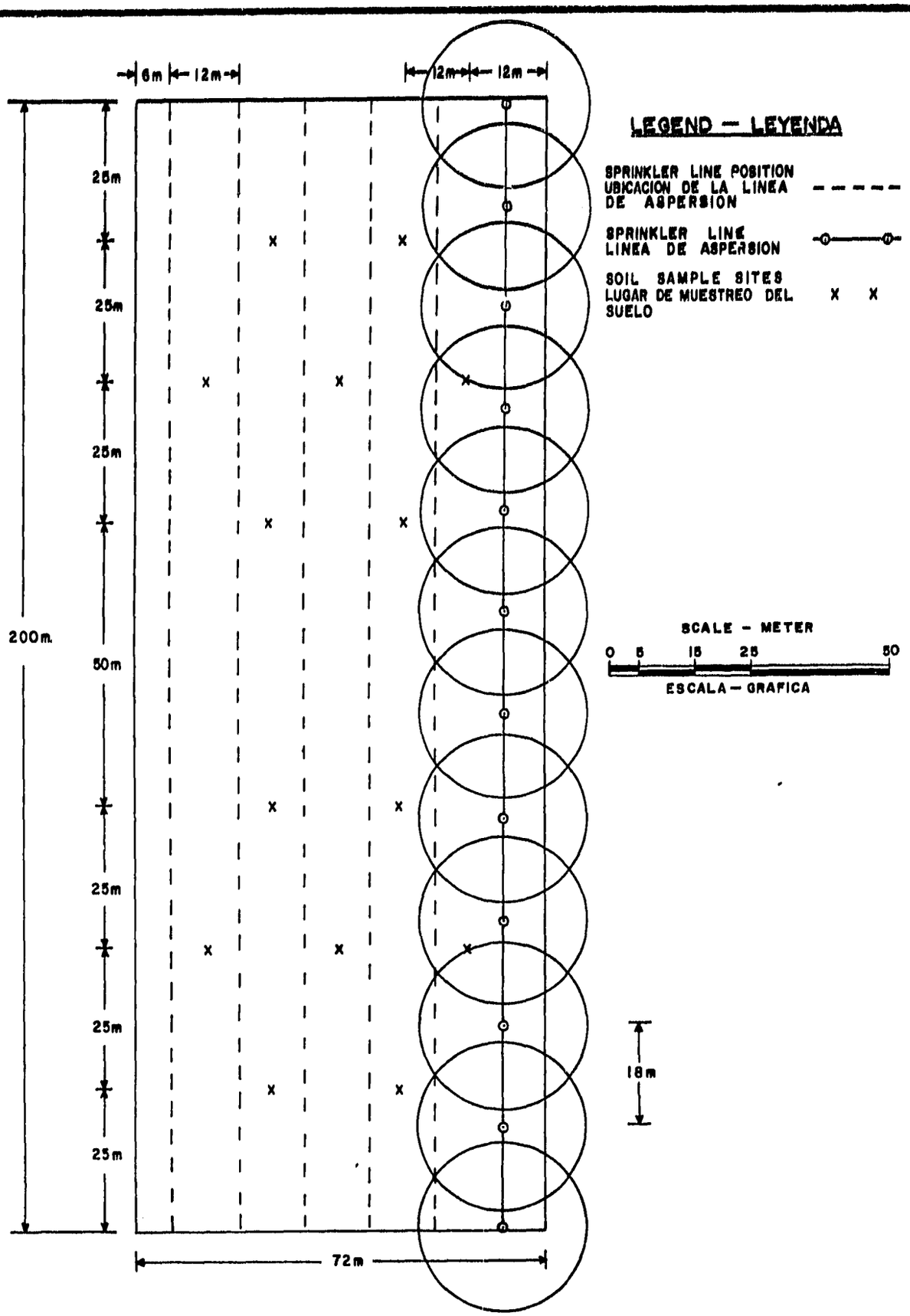


FIGURE 2.— PLOT DESIGN FOR SPRINKLER LEACHING TEST.

FIGURA 2.— DISEÑO DE LA PARCELA PARA EL ENSAYO DE LIXIVIACION POR ASPERSION

Table 3.- Average Physical Properties of the Project Soils

| | |
|---|---|
| Bulk Density, $A_s$ | 1.7 |
| Field Capacity, $P_{w1}$ | 9.2% (by dry weight) |
| Wilting Point, $P_{w2}$ | 4.4% " |
| Available Water, $P_w$ | 4.8% " |
| Infiltration Rate, i | 1.8-14.0 cm/hr |

Pre-Irrigation.- An initial pre-irrigation will be applied to the plot to bring the soil in the top meter of the profile up to field capacity. Using the average physical properties of these soils given in Table 3 and assuming that prior to the first irrigation the soil is absolutely dry, this will require 15.64 cm of water as shown by the following computation:

$$d = \frac{P_{w1} A_s}{100} D = 0.092\ (1.7)\ (100) = 15.64 \text{ cm}$$

where:

d = the depth of water required, cm

D = the depth of soil, cm

The sprinkler system will operate under the design characteristics shown in Table 4.

The time required to fill one meter depth of soil, $T_p$, will be:

$$T_p = 15.64 \text{ cm} / 0.66 \text{ cm/hr} = 23.7 \text{ hr}$$

If one lateral is used it will require about 6 days of continuous operation to pre-irrigate the entire plot. However, wind could be a factor which could interfere with the operation.

Table 4. - Design Characteristic of the Sprinkler System

| | | |
|---|---|---|
| Operating Pressure | 2.5 Atm | (36.75 psi) |
| Nozzle size | 5.0 mm | (12.5/64 in) |
| Sprinkler spacing | 18 m | (59 ft) |
| Lateral spacing | 12 m | (39 ft) |
| Lateral length | 198 m | |
| Lateral diameter | 3 in | |
| Sprinklers per lateral | 12 | |
| Sprinkler discharge | 0.3785 l/sec | (6.0 gpm) |
| Lateral discharge | 4.54 l/sec | (72.0 gpm) |
| Application rate | 0.66 cm/hr | (0.26 in/hr) |
| Lateral friction loss | 0.13 Atm | (1.9 psi) |

The experiment will not be conducted during the hours of strong wind. This will probably limit the time of irrigation to only 15 hours per day. In this case about 10 days will be required to pre-irrigate the plot. Night irrigation may be useful in increasing the possible hours of daily operation. If two laterals are used, all of the above times will be reduced by one half.

Soaking. - After the pre-irrigation is complete, the soil in each lateral position will be allowed to soak for at least seven days to permit a maximum amount of dissolving of the salt encrustations to occur prior to the leaching operation.

Leaching.- The leaching operation will apply additional water in 25 cm increments in each position. The time required for each 25 cm application, $T_1$, will be:

$$T_1 = 25.0 \text{ cm} / 0.66 \text{ cm/hr} = 38 \text{ hrs}$$

Again, if one lateral is used for a continuous 24 hrs per day period, 9.5 days will be required to apply to the test plot each 25 cm of leaching water. If wind is a factor and the time of application is reduced to 15 hrs per day, 15.2 days will be needed to cover the test plot with 25 cm of water. Two laterals will reduce this time by one half.

It is anticipated that a total of 50 cm of leaching water (in addition to the 15.64 cm of pre-irrigation) will be sufficient to reduce the salinity in the top 50 cm of soil to an acceptable level for alfalfa, about 6-8 mmhos/cm in the saturation extract. If the soil sampling at the end of this step shows that the salinity is still too high, additional 25 cm applications of leaching water will be made until the salts have been reduced to the desired level.

## Physiological Evaluation

To evaluate physiologically the effect of the water application on salt removal, one 5 m by 100 m strip of alfalfa will be planted along a centerline of the sprinkler positions after the pre-irrigation and after each successive 25 cm leaching application. The pre-irrigation should cause sufficient leaching of salts from the top soil layer to permit germination and growth of a young plant. The subsequent leaching periods should continue the downward salt movement ahead of the root expansion

to permit growth of the plant. The first strip of alfalfa should be planted just prior to the first 25 cm leaching period. Care should be taken that the top soil layer is not permitted to dry out and cause the new seedlings to die while the sprinkler line is positioned for leaching in other locations in the test plot. In this respect it will be necessary to irrigate the small alfalfa plants for an hour or so in between the leaching intervals for the other positions of the sprinkler lateral. This will entail moving the sprinkler line back to the alfalfa position prior to moving it to the next scheduled leaching position. The time sequence of pre-irrigation, leaching, alfalfa planting, and irrigation of the alfalfa is given in Figure 3 for one sprinkler line functioning and in Figure 4 for two sprinkler lines in operation simultaneously. The time of operation given in the figures is based on the assumption that the psinklers will be functioning only 15 hours per day. If conditions permit a longer period of daily operation, the total time will be shorter. What is important is that the lateral remain in each position long enough to have the required hours of operation to give the desired depth of applied water.

If the young alfalfa plants and evaporation are permitted to use 60 percent of the water available in the upper 15 cm soil layer, the depth of water that will need to be replaced is 0.75 cm. According to Hargreaves (1973) the monthly potential evapotranspiration during June and July will be about 9.0 cm in the test area (Table 5). This is equivalent to about 0.3 cm per day. At this rate the 0.75 cm of available water will last 2.5 days. An irrigation of 1 hour and 8 minutes will be required every 2.5 days to maintain the topsoil with sufficient moisture for the

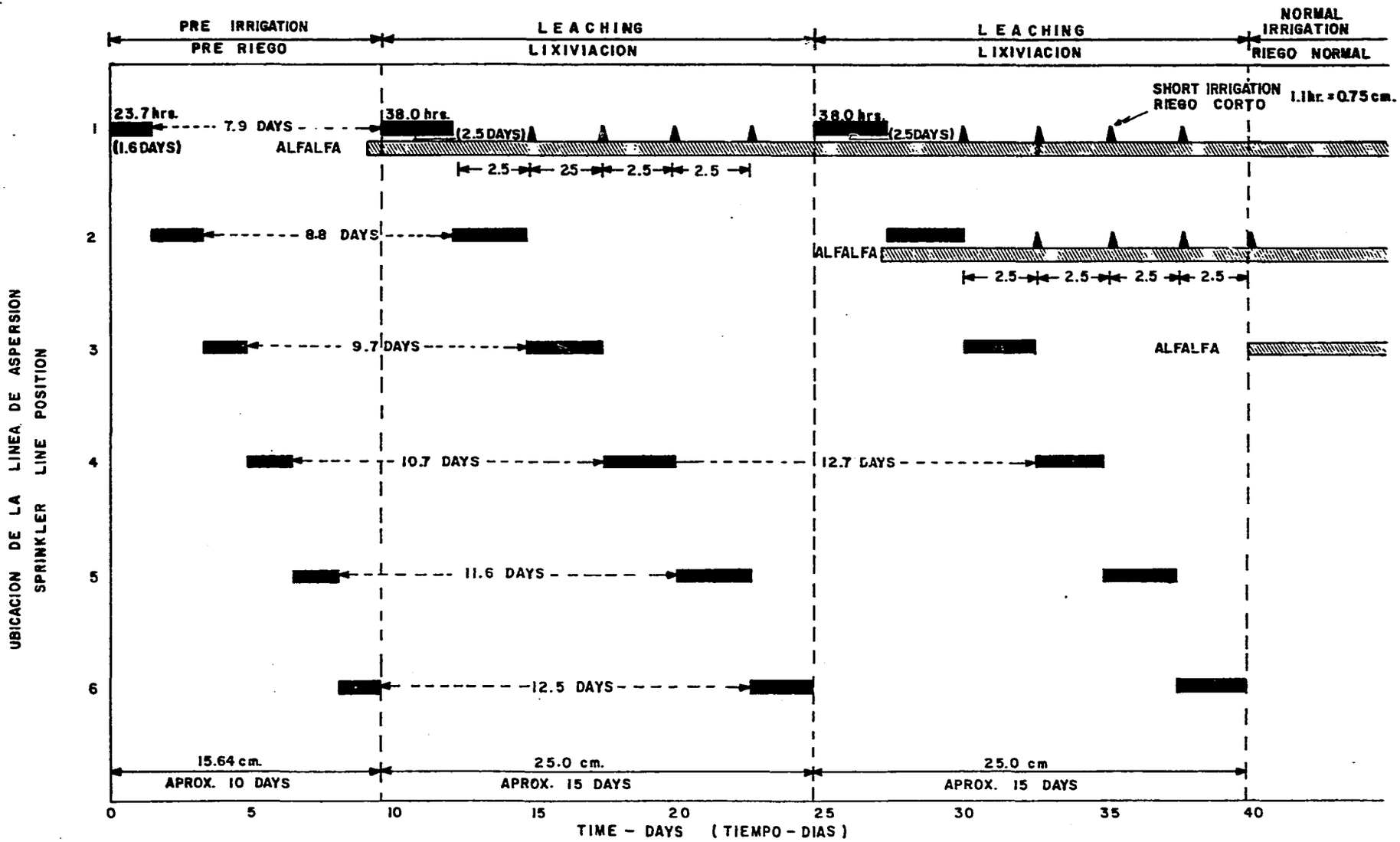


FIGURE 3.- LEACHING PROGRAM SPRINKLING 15 HOURS PER DAY WITH ONE LATERAL

FIGURA 3.- PROGRAMA DE LIXIVIACION REGANDO 15 HORAS POR DIA CON UN LATERAL FUNCIONANDO

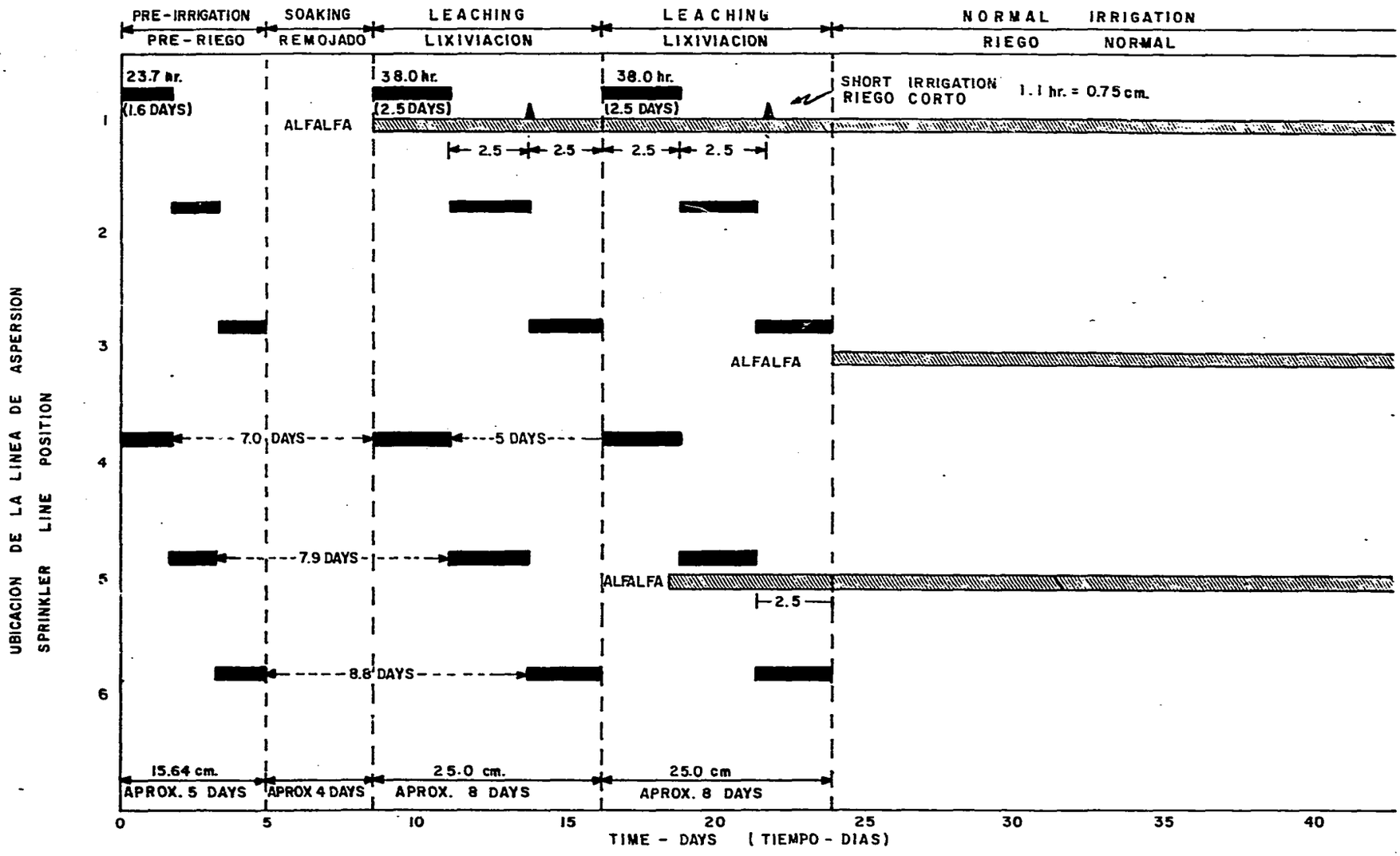


FIGURE 4_ LEACHING PROGRAM SPRINKLING 15 HOURS PER DAY WITH TWO LATERALS

FIGURA 4_ PROGRAMA DE LIXIVIACION REGANDO 15 HORAS POR DIA CON DOS LATERALES FUNCIONANDO.

seedling alfalfa. These short irrigations are indicated in Figures 3 and 4. (During other periods of the year these short irrigations will have different times of application because of varying consumptive use requirements).

Normal Irrigation Period

After the leaching period has been terminated, alfalfa may be planted to the entire plot and the planned cycle of irrigation adhered to. The design of the sprinkler system and the planned time of irrigation per setting, 5 hours, will apply a depth of water of 33 mm to the soil during each irrigation. This will wet the soil to a depth of about 40 cm. It is planned to irrigate in three settings per day which will cover the area to be irrigated (80 percent of the 5 ha plot held by each farmer) in six days.

Table 5 shows the monthly evapotranspiration (ET) for alfalfa as estimated using Hargreaves' Method (1973). Also given is the proportional amount of evapotranspiration for six day and seven day intervals during each month of the year. It is apparent that the planned depth of application of 33 mm will not meet the evapotranspiration requirements during January, November and December with a six day irrigation frequency, and it will not be sufficient in January, February, March, October, November, and December if a seven day frequency of irrigation is used (this would be the frequency if no irrigation was done on Sunday).

These observations do not consider the necessity of applying an amount of water in excess of the consumptive use of the crop to maintain a downward movement of salts through the soil profile.

Table 5. Evapotranspiration* and Irrigation Requirement in the La Joya Project, Peru

Latitude: 16°44' S

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature, °C | 19.9 | 20.1 | 19.6 | 18.6 | 17.7 | 15.7 | 16.4 | 16.4 | 17.4 | 18.2 | 18.3 | 19.0 | |
| TMF, °F | 68 | 68 | 67 | 65 | 64 | 60 | 62 | 62 | 63 | 65 | 65 | 66 | |
| Relative Humidity, % | 63 | 66 | 66 | 60 | 50 | 50 | 43 | 45 | 47 | 44 | 49 | 56 | |
| F | 2.760 | 2.349 | 2.319 | 1.891 | 1.632 | 1.427 | 1.540 | 1.809 | 2.103 | 2.504 | 2.631 | 2.799 | |
| CH | 1.0 | 0.968 | 0.968 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | |
| ETP, mm | 188 | 155 | 150 | 123 | 104 | 86 | 95 | 112 | 132 | 163 | 171 | 185 | 1664 |
| ET alfalfa, mm | 188 | 155 | 150 | 123 | 104 | 86 | 95 | 112 | 132 | 163 | 171 | 185 | 1564 |
| ET alf.(6 days), mm | 36 | 33 | 29 | 25 | 20 | 17 | 18 | 22 | 26 | 32 | 34 | 36 | |
| ET alf.(7 days), mm | 42 | 39 | 34 | 29 | 23 | 20 | 21 | 25 | 31 | 37 | 40 | 42 | |
| $D_{iw}$(6 day frequency) mm | 40 | 37 | 32 | 28 | 22 | 19 | 20 | 24 | 29 | 36 | 38 | 40 | 1848 |
| $D_{iw}$(7 day frequency) mm | 47 | 43 | 38 | 32 | 26 | 22 | 23 | 28 | 34 | 41 | 44 | 47 | 1845 |
| $T_{iw}$(6 day freq) hr:min | 6:04 | 5:36 | 4:51 | 4:15 | 3:20 | 2:53 | 3:02 | 3:38 | 4:24 | 5:27 | 5:45 | 6:04 | |
| $T_{iw}$(7 day freq) hr:min | 7:07 | 6:31 | 5:45 | 4:51 | 3:56 | 3:20 | 3:29 | 4:15 | 5:09 | 6:13 | 6:40 | 7:07 | |

* Based on Hargreaves' Equation: ETP = F (TMF) (CH)

Where:

ETP = Potential Evapotranspiration, mm
F = Factor based on latitude, mm
TMF = Mean monthly temperature, °F
CH = $0.166\ (100 - RH)^{1/2}$
RH = Mean monthly relative humidity, %

LR = 0.1
Appl. Rate = 6.6 mm/hr
$T_{iw}$ (planned) = 5 hr
$D_{iw}$ (planned) = 33 mm

Leaching Requirement

In order to maintain a favorable salt balance in the soil after the initial leaching has been accomplished, an amount of water in excess of the consumptive use requirement of the crop must pass downward through the soil. This excess amount of water is referred to as the leaching requirement.

It is determined by the following relationship:

$$LR = D_{dw}/D_{iw} = EC_{iw}/EC_{dw}$$

where

$$D_{iw} = D_{dw} + D_{cw}$$

and

$LR$ = Leaching requirement

$D_{dw}$ = Depth of drainage water to pass through soil

$D_{iw}$ = Depth of irrigation water

$D_{cw}$ = Depth of consumptive use

$EC_{iw}$ = Electrical conductivity of the irrigation water

$EC_{dw}$ = Electrical conductivity of the drainage water

Using the following values the leaching requirement can be determined:

$$LR = EC_{iw}/EC_{dw} = 0.8/8.0 = 0.10$$

Therefore,

$$D_{dw} = LR\ (D_{iw}) = LR\ (D_{dw}+D_{cw}) = 0.1\ (D_{dw}+ 1664)$$

$$D_{dw} = 184 \text{ mm}$$

$$D_{iw} = 1664 + 184 = 1848 \text{ mm}$$

The total depth of irrigation water required to achieve the necessary additional leaching to maintain a level of salinity acceptable for alfalfa

is 1848 mm per year. The planned depth of irrigation of 33 mm on a six day frequency will provide 2008 mm annually which is more than required. As noted above, however, there will be monthly evapotranspiration deficiencies. A seven day irrigation frequency will apply only 1716 mm annually at 33 mm per application. In addition to incurring evapotranspiration deficiencies during six months of the year, the total depth applied on the seven day frequency will not meet the annual leaching requirement.

Table 5 also shows the depth of irrigation water, $D_{iw}$, required for both a six day and a seven day irrigation frequency to provide both the evapotranspiration and the leaching requirements (LR = 0.1). If a 33 mm application depth is adhered to, Table 5 indicates that there will be a 5 month combined (evapotranspiration and leaching) deficiency for a six day irrigation frequency and a 6 month deficiency for a seven day frequency.

## Time of Irrigation

The times required to apply the necessary depths of irrigation water, $T_{iw}$, are also tabulated in Table 5 for each irrigation frequency. The maximum time for the six day interval is 6 hr 4 min in January and December. At three settings per day this would require 18 hr 12 min instead of the planned 15 hr to apply the necessary amount of water. Less than the 15 hr would be adequate for several months of the year (8 hr 39 min in June).

Using a seven day irrigation frequency would require 21 hr 21 min to irrigate three settings per day in January and December. This longer

time of irrigation during a day would probably be unacceptable because it would extend the irrigation into the hours of extreme wind.

From the standpoint of evapotranspiration requirements, leaching requirements, and wind, a six day frequency of irrigation for application times as tabulated in Table 5 are recommended. If a seven day frequency is used there will be the additional disadvantage that the flow of water in the river during the one day of non-irrigation will be wasted.

It is also suggested that during the first year of operation, a minimum of 5 hr per irrigation setting be practiced. This will apply an excess of water during the months of March through September which will continue the initial leaching process. During the second and succeeding years, the times of application tabulated in Table 5 should be adhered to. These times can be exceeded on occasion, but they should not be diminished if a favorable salt balance is to be maintained.

## SUMMARY AND RECOMMENDATIONS

A program of leaching the Moro-Moro soil series by the use of sprinkler irrigation has been presented. The leaching process is to be evaluated by taking sufficient soil samples to monitor the effect of the applied water in reducing the electrical conductivity of the 1:1 extract of the soil solution. Also a strip of alfalfa will be planted prior to the leaching and after every 25 cm of applied water to determine at what stage of the program a crop may be planted.

A schedule of irrigation has also been presented which will maintain a favorable salt balance in the root zone after the soils have been initially leached.

It is recommended that:

1. Prior to leaching, the soils are irrigated to field capacity to allow the salt crusts to dissolve. This will require about 16 cm of water.

2. An initial leaching of 50 cm be applied, and the salt status of the soil determined. If necessary, additional 25 cm increments may be applied until the desired level of salinity is obtained.

3. It be determined at which stage of the leaching process a crop of alfalfa may be planted by planting a test strip of alfalfa after the pre-irrigation and after each successive 25 cm increment of leaching water. Care must be taken that these

test strip are maintained with sufficient soil moisture and nutrients while the leaching process is in progress at other sprinkler positions.

4. Following the leaching process the alfalfa will be irrigated according to the evapotranspiration and leaching requirements of the crop.

5. A six day frequency of irrigation be followed using a variable time of irrigation. The time of irrigation will vary from a maximum of 6 hr 4 min per setting in January to a minimum of 2 hr 33 min per setting in June.

6. During the first year of operation a minimum of 5 hr per setting be utilized to provide additional deep leaching.

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