Quality of Irrigation Waters

primarily determined by mineral constituents and the total salt concentration in water applied for agricultural purposes

L. D. Doneen and D. W. Henderson

A water deficiency in some areas of the state, a growing population, with added irrigated acreage will increase the use and re-use of agricultural waters and tend to pollute and degrade them to the point of becoming a serious problem.

The deterioration in quality of irrigation water is due primarily to the increase in mineral constituents and the total salt concentration.

Ground waters usually contain more salts than the overlying surface waters. This may be the result of increasing the salt of the surface waters as they pass through the surface soil by evaporation or plant transpiration and, or, dissolving minerals as the water percolates through soil and rocks to the ground-water basin.

State-wide, the quality of the irrigation water can be considered in very broad generalities only. The surface waters north of San Francisco Bay are low in salts—usually ranging from 1/10 to ½ ton of salt per acre foot of water. This is also true of waters from the Sierra Nevada range, particularly the rivers flowing to the west. In the Coast Range, moving south from San Francisco the trend is toward an increase in salts, with probably the highest concentration in the Santa Maria and Cuyama Rivers, which sometimes contain over two tons of salt per acre foot of water. In general, southern California rivers carry considerably more salts than the streams of northern California, with the Colorado River having about one ton of salt per acre foot of water.

About 50% of the irrigated land in California is irrigated from underground basins, and to isolate particular areas of poor and good well waters is not easy. They may vary from about 1/5 ton to over four tons of salt per acre foot, excluding oil field brines, which are much higher. Probably the largest areas of rather poor well waters are those of the west side of the San Joaquin Valley. Most of these waters are relatively high in total salts. The wells in the Coastal mountains and valleys—and other isolated areas throughout the state—may have relatively high salt waters.

The composition of well waters may be variable even within a short distance. Wells of good quality water—low in total salts—may be a mile or two away from a well containing poor quality water.

A research program—to find means of determining the suitability of irrigation waters for crop use—includes work along three broad bases: *1*, the total salt concentration; *2*, the amount of sodium and its relationship to other salts; and *3*, individual constituents, or salts that might be harmful or toxic to plants. Besides the minerals in the water, other factors are being studied, such as climatic conditions—principally rainfall—soil type, drainage, irrigation management and type of plant grown.

In general the more salt a water contains the poorer its quality. However, there are many exceptions and under certain conditions some salts may be tolerated by plants without harmful effects. In most of the irrigation waters total salt concentrations are not sufficiently high to be injurious to plant growth, but rather their accumulation in the soil produces salines. This is brought about by evaporation from the soil surface and the use of water by plants through transpiration, leaving the salts to accumulate in the soil with each succeeding irrigation. Plants remove only small quantities of salt from the soil, which may be less than 1% of the salt added from a water of moderate salinity. A saline soil may be the result.

Certain salts in irrigation water—lime

Application of gypsum to irrigation water increases infiltration for high per cent sodium and low total salt waters.

salts and gypsum—do not contribute to the salination of a soil. They have a limited solubility and will precipitate upon concentration of the soil solution or when the soil dries. Therefore, they do not accumulate as soil salines. The remaining soluble salts have been termed the effective salinity of an irrigation water. These soluble salts are calcium chloride, magnesium sulfate and chloride, and all the salts of sodium—bicarbonate, chloride and sulfate.

Many waters of the state contain appreciable quantities of lime salts—calcium-magnesium carbonate—and consequently the effective salinity of these waters is considerably less than the total salt concentration would indicate. For example, 375 waters used for the irrigation of citrus in Ventura County had an effective salinity of 50% of the total salts. These waters average a salt concentration of 3,340 pounds per acre foot of water, and by most standards are considered in the intermediate or poor quality class. Citrus is considered to be among the most sensitive of all crops grown in California and apparently its successful production in Ventura County is due primarily to the precipitation of half the salts in the irrigation water.

In Lake County where 104 irrigation waters have been studied, the effective salinity was only 27% of the total salts.

A third example of calcium-magnesium carbonate waters is found in the Putah and Cache Creeks in Yolo County, where the water contains about 2,000 pounds of salts per acre foot. The effective salines of these waters average about 560 pounds per acre foot or a reduction of 72% of the total salts.

Some waters upon concentration precipitate few salts, particularly those high in sodium or chloride. With these waters total concentration is a fair measure of effective salinity.

The annual rainfall is a very important consideration in judging the suitability of an irrigation water. In areas of high rainfall such as the Sacramento Valley where the soil is wet to 6′ or more in depth—below the depth of rooting of the crop grown—the salinity of an irrigation water could be relatively high due to its natural removal.

It apparently is not necessary to have

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Reclaimed Water

sewage effluents as source of irrigation water attracting increasing attention

H. A. Schreiber

About 10% of the developed water supply in California is used for domestic or industrial purposes and 90% for crop irrigation.

As fresh water supplies capable of being developed in California are dwindling, interest in sewage effluents as a source of irrigation water is increasing. However, not all of the sewage effluent is presently recoverable.

State law prohibits the use of untreated sewage for irrigation, although sewage which has received a complete treatment—including disinfection—may be used as any other water source. Sewage which has received a partial treatment, such as passage through a septic tank, an Imhoff tank or the like, may be used for purposes which do not result in produce which would be eaten by humans in an uncooked state or on pastures for milk cows.

Advantages in using reclaimed sewage effluents will vary with the degree of treatment of the raw sewage, its quantity and its mineral quality, the crops grown, their water requirements, and the soil conditions.

The inorganic quality of reclaimed water may not differ greatly from the fresh water supply in regions of the state that have naturally low concentrations of salts. In some areas the natural waters have sufficient mineral salts to warrant water softeners. In other areas contaminants from industry are sufficient to increase drastically the effluent's sodium and chloride content. As with fresh water, the concentration and relative composition of salts determine in many instances what crops can be grown within an area. The commonest uses for this type of water are irrigated pasture, alfalfa, cotton and other agronomic crops. However, citrus and avocados are reported to be doing successfully within their climatic and soil zones provided salinity in the effluent is not a problem.

Large cities bordering the Pacific Ocean discharge effluents usually contaminated with heavy amounts of inorganic salts. To make such water suitable for irrigation, the purely industrial contaminants—such as brines and stable organic chemicals—must be separated from domestic sewage, which could be done through zoning restrictions and the use of dual sewer systems. In addition, land capable of supporting irrigation agriculture frequently is some distance from the treatment plants, necessitating costly pumping and aqueduct facilities. Criticisms directed toward the proposed use of reclaimed water have disappeared after actual use.

The supply and demand of reclaimed waters are possibly the most important considerations. In some cases the quantity of effluent available will be supplemental to other sources of supply for optimum crop production. The quantity available is continual, even in years when other sources are in short supply. Also there is a tendency for maximum production of sewage during the summer seasons of high crop consumption. In what might be considered another type of supply, the quantities of effluent available are in excess for optimum crop production. In both cases the usual agreements are for the farm operator to use all the water. This often necessitates construction of lagoons for single farms, or groups of farmers entering into agreements to share in this water storage problem during seasons of low crop demand for irrigation.

In some situations where soil permeability is high, use of this excess water is successfully made in preplant irrigation treatments. Additional advantages exist in this latter use in that considerably higher organic matter concentrations can be applied without harm to the following crop.

Soils that are receiving sewage effluents in various stages of treatment cover the textural range. The same rules for obtaining satisfactory yields with other sources of water apply to effluents, except in the case of sandy soils and preplant irrigation treatments. Due to the organic matter content in these reclaimed waters, the coarser textured soils tend to improve relative to many of their physical properties. Clay soils could tend to seal unless cultivated occasionally. Disking or plowing appears to be adequate for land cropped annually and simple harrowing of perennial pastures serves as a preventative where needed. No cumulative injuries to water penetration have been noted. A better tilth can be observed on clay soils, and actual reclamation of alkali soils has occurred through the use of sewage effluents of good inorganic quality.

Delivery of reclaimed water can be done by the same types of distribution systems used with fresh waters. A few users have reported difficulties due to clogging of screens in pressure systems, but this is correctable. Ditches may become coated with an unsightly layer of sludge if the effluent has received a minimum of treatment.

In some areas of the western United States the effluents are considered to be very valuable. In most instances these locations are where rainfall is very low and usually where the growing season is rather long. Usually, if a choice is available, operators prefer an effluent with a minimum of treatment, due to the higher content of nutrients. In every reported case, yields have been equal—usually superior—to those obtained using fresh water.

An examination of chemical analyses of typical effluents of 15 California cities shows that the element nitrogen, occurring chiefly as ammonia, is present to the extent of 60–100 pounds per acre foot of water, 20–40 pounds of potassium as potassium and 60–100 pounds of phosphates as phosphate. These are appreciable quantities of important elements. It is reported that many pastures and golf courses are entirely self-supporting, regarding fertilization, and further, that stands are established more quickly.

Where laws and crop usage permit reclaimed water, returns in increased yields compared to those obtained from use of conventional sources of water are being realized. Frequently, double value is obtained because a disposal problem of a municipality is alleviated by agricultural use of reclaimed water.

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sufficient rain to wet below the rooting depth of the plants each year, but a rainfall that will wet to this depth every three or four years may be sufficient to prevent excess accumulation of salts in a soil. This has been borne out from the Ventura County investigations. During a period of three or four consecutive years of extremely low rainfall, when the rain water did not penetrate below the rooting depth, there was considerable salt injury to lemon leaves. But with one or two years of normal or above normal rainfall the salines were effectively removed from

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WATER-SOIL-PLANT

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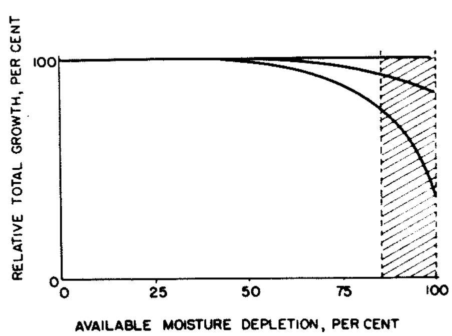
whether growth or yield in given situations is likely to be unaffected by depletion of nearly all the available water as measured by present methods or is likely to be increased by irrigation at lower soil moisture stresses. The following two check lists may be helpful in anticipating the response of crops when given conditions prevail. It is not implied that all conditions must be present, nor is the relative weighting of each condition considered. If a given situation is described by some entries from both tables, prediction of response to irrigations will be much more difficult.

It is often questionable whether the increased yields sometimes obtainable with relatively frequent irrigations will pay for the added cost of water and labor. The following practical considerations all suggest the desirability of using irrigation water sparingly: maximium use of limited water supply, water and nutrient losses caused by deep percolation, danger of developing a drainage problem through overirrigation, maintenance of favorable soil tilth and, in some cases, obtaining high quality of the marketable product. Frequent irrigations often aggravate the problems of plant diseases, insects and longevity in perennial crops. Although these considerations are of real importance in determining farm irrigation practices, their relative importance differs from place to place and even from year to year.

To assure a continuous supply of available soil moisture and to allow for unforeseen delays in irrigation or unusually dry weather, the irrigation farmer generally can not allow nearly complete available soil moisture depletion. To allow for a margin of safety, he should plan to irrigate while some available moisture still remains. The fraction of the total available moisture range which can be utilized with safety depends on a number of factors including crop rooting characteristics, the soil and the irrigation system. If, as illustrated below, a safety margin of 15% is made to meet the practical problems of irrigation under farming conditions, then a considerable portion of the differences predicted by the several current theories on water-soil-plant relations tends to disappear. However, to raise irrigation efficiency and to increase crop production, vigorous programs of research must be continued.



Some Conditions Which Will Increase or Decrease the Probability That Crop Yields Will Be Reduced by Allowing Nearly Complete Depletion of Available Soil Moisture

	Increased Probability (Relatively frequent irrigation desirable)	Decreased Probability (Relatively infrequent irrigation possible)
Plant	Shallow, sparse, slow-growing roots	Deep, dense, fast-growing roots
	Fresh weight yield of vegetative organ desired	Dry weight yields of reproductive organ desired
	Quality dependent upon size of vegetative organ	Harvest for content of sugar, oil, etc.
Soil	Shallow soil; poor structure impeding root growth	Deep soil; good structure
	Slow infiltration and internal drainage; poor aeration	Good infiltration, internal drainage, aeration
	Root disease, nematodes present	Large fraction of available water held at low soil moisture stress levels
	Small fraction of available water held at low soil moisture stress levels	Nonsaline
	Saline soils or water	Fertility level low; nutrients distributed in profile
	Fertility level high; nutrients concentrated in topsoil	Constant water table in reach of roots
Weather	Planted at beginning of hot dry season	Planted well ahead of hot dry season
	Major growth period during hot dry season	Major growth period before hot dry season
	High evaporation rates	Low evaporation rates

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The studies on sugar beets were conducted by L. D. Doneen, and those on beans by L. D. Doneen, Professor of Irrigation, and D. W. Henderson, Assistant Professor of Irrigation, University of California, Davis.

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the root zone and the salt injury to the trees disappeared.

The type and condition of the soil determine to some extent the hazards of salt accumulation from salines in the irrigation water. On open and well drained soils where deep percolation of water is easily accomplished the effective salinity can be much higher than on poorly drained soil where there is a high water table. Many soil conditions—stratified soils, clay lenses, some clay and adobe soils, dense or compact subsoils, heavy clay subsoils—may seriously reduce deep percolation of the irrigation water in a reasonable time. These soil conditions may prevent sufficient leaching to remove the salines from an irrigation water having an appreciable amount of salts.

Another important consideration in judging quality of water is the quantity of water that penetrates below the root zone. In low rainfall areas, as the San Joaquin Valley and the Imperial Valley some leaching may be desirable, but because 20%–70% of the water applied may penetrate below the rooting depth of plants, most surface soils are adequately leached of excess salts. It is nearly impossible to adequately irrigate any sizable area for maximum production without some deep percolation of the water. With careful control of the water there will be sufficient leaching to maintain a low salinity in the root zone for most plants.

Sodium content or percentage of the total salts is very important. If the per cent sodium is low good friable soil structure is maintained and soil will take water readily. However, if the sodium percentage is high the soil will disperse—the structure destroyed—and the rate of water infiltration will be reduced. In extreme conditions of dispersal, the soil will be effectively sealed against the penetration of water so it remains on the surface until it evaporates or is removed by surface drainage. Some quality of water standards have indicated that when 60% or more of the salts are sodium, trouble can be expected from soil dispersal and reduced water penetration. Recent investigations indicated this it not necessarily a simple percentage relationship, but the role sodium plays has not been entirely investigated. For example, with the precipitation of the lime salts in the soil—calcium and magnesium carbonate—the sodium percentage of the soil solution will increase over that of the original irrigation water. This increase in sodium percentage may be sufficient in some cases to cause a dispersal of the soil and reduce the rate of water infiltration. This may be particularly serious where the irrigation water contains more bicarbonate ion than calcium and magnesium. This type of water occurs from wells in an area of about 18,000 acres north of Bakersfield in Kern County. These waters are low in total salt but the principal salt is sodium bicarbonate. To successfully use these waters for irrigation, they must be amended by the addition of gypsum.

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30′ would be satisfactory with wind velocities up to 7–8 mph. In all cases, the closer sprinkler and lateral spacings were most satisfactory.

Spacings Tested During Summer of 1956

Sprinkler		Lateral
20′	x	40′
	x	50
	x	60
30	x	40
	x	50
	x	60
40	x	50
	x	60
60	x	80

To evaluate the importance of sprinkler and lateral spacings on distribution under actual field conditions, nine different combinations of sprinkler and lateral spacings were tested during the summer of 1956. The spacing combinations are shown in the next column.

All the laterals were operated simultaneously except for a small difference in time required because of slightly different application rates. At the end of each run, the necessary measurements were made, the lateral moved and the process repeated. This procedure required two days of operation for four lateral positions and was carried out on a 24 hour basis—two day and two night runs.

A test plot was established between the second and third lateral positions for each lateral and sprinkler spacing and equipped with collection cans set on a 10′ grid pattern and read at the end of each period of operation.

The rates of discharge of the sprinklers were determined periodically by volumetric measurements. Pressures were maintained by careful regulation and use of calibrated pressure gages. Records of temperature, humidity, wind direction and velocity were obtained for all test periods.

During five irrigations the average wind velocity did not exceed 7.2 mph for any 24 hour period. During most of the periods of water application wind velocity varied from 2–5 mph and from essentially the same direction. The maximum daytime temperature was 98°F. The nighttime temperature varied between 57°F and 64°F. These weather conditions were typical for summertime in the test area. It was not exceptionally windy or hot.

Data for two of the irrigations with different average wind conditions are shown in the following table. A direct comparison of the uniformity coefficients for all spacing combinations shows a significant decrease in uniformity when the wind velocity increased from 2.8 to 6.4 mph. This information confirms the reliability of results obtained by shorter single lateral tests.

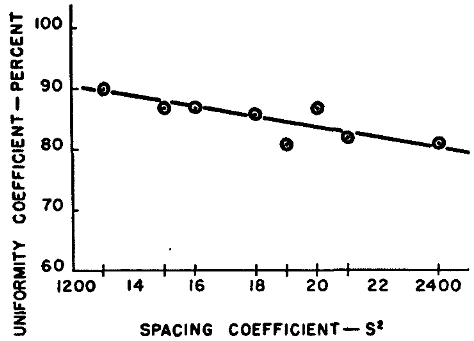
Wind velocity avg. per irrig.	Sprinkler Spacing								
	20			30			40		60
	Lateral Spacing								
	40	50	60	40	50	60	60	50	80
mph	Uniformity Coefficient—Per cent								
2.8	94	93	83	93	90	91	86	86	70
6.4	81	75	72	77	77	74	73	70	62

To evaluate the performance of the different spacings results were plotted as a relationship between the uniformity coefficient and a spacing coefficient. The spacing coefficient is a numerical expression computed by dividing the square root of the area within the sprinkler and lateral spacing by the sprinkler diameter throw. The graph on this page shows that in general the greater the spacing coefficient or area between sprinklers and laterals, the lower will be the uniformity of water distribution.

Specifically, the uniformity for the 30′ sprinkler spacing by 40′, 50′ and 60′ lateral spacings are quite similar. In fact, there is essentially no difference between any of these lateral spacings for the type of sprinklers used in these tests. Essentially the same results were obtained for the 40′ by 50′ and 60′ lateral spacings.

A 10′ difference in lateral spacing for sprinklers 20′ or 40′ apart and a 20′ difference for the 30′ sprinkler spacing makes little difference in the uniformity

Relationship between uniformity coefficients and spacing coefficients.



of water distribution when operating under typical field conditions and wind velocities did not exceed 6–7 mph.

Comparing results obtained for the different sprinkler spacings—20′, 30′, 40′ and 60′—the 30′ spacing was the best, followed by the 20′ by 40′ and 50′ spacings, and then by either the 20′ by 60′ or 40′ by 50′ spacings. In all cases the large sprinklers operating on the 60′ by 80′ spacing were considerably poorer.

Therefore, in order to achieve as uniform coverage as possible, these tests indicate that the choice would lie between spacings of 20′ by 40′ or 50′ and 30′ by 40′, 50′ or 60′. Since there was only a small difference in the uniformity coefficients for these spacings, the selection would then depend upon other considerations, such as the difference in the number and cost of sprinklers and couplers required for the 20′ and 30′ spacings and the labor required to move the pipe for these spacings.

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Recently investigations have indicated that with waters having an appreciable quantity of salt—from one to three tons per acre foot— the sodium percentage can be higher than with waters of low salt concentration, and still maintain fair infiltration rates. Examples of this type of water occur on the west side of the San Joaquin Valley where many well waters contain from one to three tons of salt per acre foot, with a sodium percentage of 60%–90%.

Investigation under way at present indicates there are at least two soil series that did not disperse or reduce infiltration rates when irrigated with a high percentage sodium water as is the case with many soil series. The role the soil series or type plays in relation to water quality is being investigated.

Probably the most widely recognized toxic salt occurring in some California irrigation waters is boron, which is toxic in very low concentrations. Irrigation water containing little more than ½ part per million of boron may cause injury to sensitive plants. In other cases one or more parts per million will be required to produce injury. Three or four parts per million is usually considered the upper limit for the more tolerant crops.

Sodium may be toxic to certain plants. This element is usually accompanied by the chloride ion and either one or both may cause burning or death of leaves in lemons, oranges, almonds, apricots, peach and walnuts. Beans and potatoes are also sensitive to these elements. Burning and killing of plant leaves is not necessarily associated with a high salt concentration in the soil, for upon analyses no high concentration of salts is found, and many times it is quite low.

Recently, work has indicated a sulfate toxicity to certain strains of lettuce and romaine. Earlier this was known as Brown Blight, which occurs principally

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MOVEMENT

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phere suction value—about 75% of the available water has been removed from the Fallbrook soil and approximately 60% from the Holtville soil.

Further studies of moisture extraction from soils are being made under controlled conditions without using plants. Soil columns are positioned horizontally and brought to equilibrium with water at approximately 30 millibars. This is often a value read on tensiometers following an irrigation in the field. A constant suction is then applied at one end of a soil column, by applying a controlled vacuum to one side of a porous ceramic disc the other side of which is in direct contact with the soil. The lower left graph on page 24 shows the accumulated water extracted from soil columns when the suction of 900 millibars was maintained constant. The extracted water was measured in surface inches in relation to the area of the soil column.

In the same length of time, 80% more water was extracted from a column of soil 14″ long compared with the same column when it was cut down to 7″ in length. This would indicate that, for this Fallbrook sandy loam, root-free portions of the soil 7″ away from roots can make substantial contributions to water extracted by roots.

Soils vary greatly in their ability to conduct water. A comparison of three soil types shows that under the same controlled laboratory conditions the water extracted from a Ramona sandy loam soil was approximately twice as much as from a Fallbrook sandy loam and threefold that from a Yolo loam. The curves comparing various soils were all obtained using 14″ soil columns.

For these studies of soil moisture movement, fragmented soil samples were screened and compacted in the columns. Further studies will be made on undisturbed cores.

If only moisture flow rates are measured—to compare the ability of various soils to conduct water—the size and shape of the soil sample and suction equipment would need to be standardized. However, when continuous records of the moisture suction values are obtained at various locations along the soil column, as well as moisture extraction rates, computations can be made expressing the conductivity values of a soil as a function of the moisture suction. These values are characteristic of the soil and independent of the methods of measurement. They can be used to characterize different soils or study the effects of soil management practices on the same soil. Also, when suction values in the field are measured by tensiometers, flow rates can be estimated.

Studies of moisture movement in soils in the liquid phase are made under constant temperature conditions. Thermal gradients within the soil column, which result in water vapor diffusion, can cause significant disturbances to the measured liquid flow.

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The above progress report is based on Research Project No. 1546

PENETRATION

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In most cases not enough water can be stored in the soil to last throughout the season. Where water penetration is slow, more water can be applied by irrigating more frequently or by increasing the time the water is on the land surface at each irrigation. Both approaches have advantages and limitations. More frequent irrigation may be accomplished without any other change in the system or in practice, but has the disadvantage of higher labor costs. It may be an inadequate measure for the more difficult problems. Prolonged irrigation may require substantial changes such as converting from furrows to basins in which water can be ponded for long periods or using small furrows to insure better coverage of border strips with small streams. Irrigation of crops susceptible to injury or disease under prolonged irrigation can not be managed in this way, and the practice may encourage growth of water-loving weeds. However, such methods may be the only means of increasing the productivity of soils with very slow water penetration even though changes in cropping pattern or farming operations are required.

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TEMPERATURE

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ing facility must provide for maximum energy capture, discharge water at a temperature giving maximum rice yields, occupy a minimum land area, with reasonable installation and maintenance costs.

From experience in rice irrigation, water temperature may be expected to influence the growth of other crops. However, it is difficult to predict the influence of water temperature on yields because of its numerous direct and indirect effects on the plant. In addition to the cold water damage reported here, crop injury is sometimes associated with warm water.

As more is learned about its effects on irrigated crops, water temperature may become a factor of considerable importance in the selection of crops and their management for maximum yield and minimum unit cost.

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Bruce Wylie, Glenn County rice grower; the Glenn–Colusa Irrigation District, and Milton D. Miller, Extension Agronomist, University of California, Davis, participated in the studies reported in the above article.

MEASUREMENT

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grove was on a two week irrigation schedule. The irrigation water applied July 19 and August 3 reached the 12″ soil depth but did not wet the soil at the 18″ depth to field capacity.

The time and place to use either tensiometers or blocks depends to a large extent on climatic conditions and soil types and to a lesser extent on the nature of the crop. In inland areas of southern California where high water losses may cause stress conditions in plants, timing of irrigations becomes very important. Tensiometers have proved to be valuable tools for timing irrigations in citrus and avocado groves. However, in the more humid areas where irrigations are intermittent, along with rainfall, resistance blocks are used with satisfactory results. Resistance blocks made of gypsum rather than fiberglass or nylon are generally preferred in agricultural soils.

The neutron method is still a research tool although it might be valuable on large agricultural acreages.

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The above progress report is based on Research Project No. 1612.

QUALITY

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in the Imperial Valley. Here Colorado River water is used for irrigation and contains large quantities of sulfate, which produces this toxic symptom.

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The above progress report is based on Research Project No. 1529.