WATER ITS QUALITY, MANAGEMENT AND FIELD MEASUREMENT

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There is an ever increasing competition for available water resources of the country by domestic, industrial, municipal and agricultural interests. New controls are being initiated by various agencies to regulate, protect and allocate water resources. Water resources are limited as to quantity and are variable as to quality Use, re-use, recycling and discharge and disposal of water and waste waters are becoming increasing regulated.

Optimum use of water resources depends upon knowledge of water quality, its management and its measurement. To safe guard ones own irrigation water supplies a person must understand what effect a specific water quality has on crop yields and soil conditions and how a change in water quality will influence crop yields and soil conditions. Management of water at the field level means providing the conditions to apply the optimum amount of water uniformily to the field, at a minimum cost while obtaining the maximum yield. The amount of water delivered to the field, applied to the soil, retained in the soil and utilized by the plant are usually very different quantities.

WATER QUALITY

Water quality needs to be interpreted on the basis of specific needs and conditions. Agriculture is being expected to; accept, use and re-use lower quality water in exchange for better quality water. This is in spite of the fact that plants generally require waters having lower salt concentrations than people or animals reguire.

An alfalfa grower not only must be concerned with the effect of water quality on alfalfa but on the other crops with which alfalfa is rotated in addition to its effect on the soil. All irrigation waters contain some salt. Salts may be beneficial or harmful depending upon the kind of salts and their concentration. The kinds of salts and their concentration is varied. When it is necessary to accept or use lower quality water additional costs may be expected from increased water needed for leaching, lower crop yields from higher salt waters, from lower quality products and from more management and supervision.

The major problems related to water quality are salinity, toxicity and permeability. The evaluation of water quality begins with a water analysis for Electrical Conductivity (EC), Calcium (Ca), Magnesium (Mg), Sodium (Na), Carbonate (CO_3), Bicarbonate (HCO_3), Chloride (Cl), Sulfate (SO_4), Boron (B), Nitrate Nitrogen (NO_3-N), pH and other constituents as may be necessary.

The guidelines on the following pages for interpreting water quality were developed by the U.C. Committee of Consultants. The explanation for the guidelines are included.

The complete guidelines are available from the county Cooperative Extension offices. Table 1 provides values for the calculation of pHc values of water. The table also provides the formula for calculating the S.A.R. There are numerous other tables associated with the guidelines which should be consulted for more specific interpretations. Table 2 is a composite from several tables giving relative salt tolerance for some crops commonly rotated with alfalfa.

GUIDELINES FOR INTERPRETATION OF QUALITY OF WATER FOR IRRIGATION

Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

PROBLEM AND RELATED CONSTITUENT	WATER QUALITY GUIDELINES		
	No Problem	Increasing Problems	Severe Problems
Salinity[1/]			
EC_w of irrigation water, in millimhos/cm	<0.75	0.75 - 3.0	>3.0
Permeability			
EC_w of irrigation water, in mmho/cm	>0.5	<0.5	<0.2
adj.SAR[2/]	<6.0	6.0 9.0	>9.0
Specific Ion Toxicity[3/]			
from ROOT absorption			
Sodium (evaluate by adj.SAR)	<3	3.0 - 9.0	>9.0
Chloride (me/l)	<4	4.0 - 10	>10
(mg/l or ppm)	<142	142 - 355	>355
Boron (mg/l or ppm)	<0.5	0.5 - 2.0	2.0 - 10.0
from FOLIAR absorption[4/] (sprinklers)			
Sodium (me/l)	<3.0	>3.0	
(mg/l or ppm)	<69	>69	
Chloride (me/l)	<3.0	>3.0	
(mg/l or ppm)	<106	>106	
Miscellaneous[5/]			
NH_4-N, NO_3-N (mg/l or ppm) for sensitive crops	<5	5 - 30	>30
HCO_3 (me/l) [only with overhead sprinklers]	<1.5	1.5 - 8.5	>8.5
(mg/l or ppm)	<90	90 - 520	>520
pH	normal range = 6.5 - 8.4		

1/ Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Refer to tables for crop tolerance and LR. (mmho/cmX640= approximate total dissolved solids (TDS) in mg/l or ppm; mmhoX1000= micromhos)

2/ adj.SAR (Adjusted Sodium Adsorption Ratio) is calculated from a modified equation developed by U.S. Salinity Laboratory to include added effects of precipitation or dissolution of calcium in soils and related to CO_3 + HCO_3 concentrations.

To evaluate sodium (permeability) hazard:

$$adj.SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \left[1 + (8.4 - pHc) \right]$$

pHc is a calculated value based on total cations, Ca+Mg, and CO_3+HCO_3. Calculating and reporting will be done by reporting laboratory. NOTE: Na, Ca+Mg, CO_3+HCO_3 should be in me/l.

Permeability problems, related to low EC or high adj.SAR of water, can be reduced if necessary by adding gypsum. Usual application rate per acre foot of applied water is from 200 to about 1000 lbs. (234 lbs. of 100% gypsum added to 1 acre foot of water will supply 1 me/l of calcium and raise the ECw about 0.1 mmho). In many cases a soil application may be needed.

3/ Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables). For boron sensitivity, refer to boron tolerance tables.

4/ Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low-humidity, high-evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

5/ Excess N may affect production or quality of certain crops, e.g. sugar beets, citrus, avocados, apricots, grapes etc.
(1 mg/l NO_3-N = 2.72 lbs. N/acre foot of applied water).
HCO_3 with overhead sprinkler irrigation may cause a white carbonate deposit to form on fruit and leaves.

Symbol	Name	Symbol	Name	Equiv. Wt.
EC_w	Electrical Conductivity of water	Na	Sodium	23.00
mmho/cm	millimho per centimeter	Ca	Calcium	20.04
<	less than	Mg	Magnesium	12.16
>	more than	CO_3	Carbonate	30.00
mg/l	milligrams per liter	HCO_3	Bicarbonate	61.00
ppm	parts per million	NO_3-N	Nitrate-nitrogen	14.00
LR	Leaching Requirement	Cl	Chloride	35.45
me/l	milliequivalents per liter			
TDS	Total Dissolved Solids			

17.1 ppm = 1 grain per gallon

Assumptions and Comments on Guidelines for Interpretation of Quality of Water for Irrigation Developed by UC-Committee of Consultants.

1. These "guidelines" are flexible and intended for use in estimating the potential hazards to crop production associated with long term use of the particular water being evaluated. "Guidelines" should be modified when warranted by local experience and special conditions of crop, soil, method of irrigation or level of soil-water-crop management. Changes of 10 to 20 percent above or below an indicated guideline value may have little significance if considered in proper perspective along with all other variables that enter into a yield of crop.

2. It is assumed that the water will be used under average conditions - soil texture, internal drainage, total water use, climate, and salt tolerance of crop. Large deviations from the average might make it unsafe to use water which under average conditions, would be good, or might make it safe to use water, which under average conditions, would be of doubtful quality.

3. The divisions into "No problem - Increasing problem - Severe problem" is more-or-less arbitrary but based on large numbers of field studies and observations, as well as carefully controlled greenhouse and small plot research conducted by various researchers over the past 40 years or more. Guidelines of one sort or another have been proposed by U.S. Geological Survey, University of California, U.S. Salinity Laboratory and many others starting as early as 1911. As new research and observations have developed additional information for assessing water quality, guidelines have been modified.

4. These "guidelines" apply to surface irrigation methods such as furrow, flood, basin, sprinklers, or any other which applies water on an "as-needed" basis and which allows for an extended dry-down period between irrigations during which the crop uses up a considerable portion of the available stored water.

5. The guidelines incorporated some of the newer concepts in soil-plant-water relationships as recently developed at U.S. Salinity Laboratory. Uptake of water occurs mostly from the upper two-thirds of the rooting depth of crop (the "more-active" part of the root zone). Each irrigation normally will leach this upper soil area and maintain it at relatively low salinity. Salts applied in the irrigation water under resonable irrigation management concentrate in the soil water in this active root zone to about three times the concentration of the applied irrigation water and the salinity of this root area is representative of the salinity levels to which the plant responds. The salinity of the lower root zone is of less importance as long as plants are reasonably well supplied with moisture in the upper, "more-active", root zone.

These guidelines represent the 1974 consensus of the UC-Committee of Consultants. It is recognized they are not perfect and it is expected they will be modified from time to time as further knowledge and experience dictate.

TABLE

TABLES FOR CALCULATING pHc VALUES OF WATERS

pHc can be calculated, using the table below; $pHc = (pK'_2 - pK'_c) + P\,(Ca{+}Mg) + pAlk$ where $pK'_2 - pK'_c$ is obtained from Ca+Mg+Na
p (Ca+Mg) " " " Ca+Mg
pAlk " " " Co_3+HCO_3

Tables for Calculation pHc

Conct. Ca+Mg+Na (me/1)	$p(K'_2-K'_c)$	Conct. Ca+Mg (me/1)	p(Ca+Mg)	Conct. Co_3+HCO_3 (me/1)	pAlk
	2.11	.05	4.60	.05	4.30
	2.12	.10	4.30	.10	4.00
.9	2.13	.15	4.12	.15	3.82
1.2	2.14	.2	4.00	.20	3.70
1.6	2.15	.25	3.90	.25	3.60
1.9	2.16	.32	3.80	.31	3.51
2.4	2.17	.39	3.70	.40	3.40
2.8	2.18	.50	3.60	.50	3.30
3.3	2.19	.63	3.50	.63	3.20
3.9	2.20	.79	3.40	.79	3.10
4.5	2.21	1.00	3.30	.99	3.00
5.1	2.22	1.25	3.20	1.25	2.90
5.8	2.23	1.58	3.10	1.57	2.80
6.6	2.24	1.98	3.00	1.98	2.70
7.4	2.25	2.49	2.90	2.49	2.60
8.3	2.26	3.14	2.80	3.13	2.50
9.2	2.27	3.90	2.70	4.0	2.40
11	2.28	4.97	2.60	5.0	2.30
13	2.30	6.30	2.50	6.3	2.20
15	2.32	7.90	2.40	7.9	2.10
18	2.34	10.00	2.30	9.9	2.00
22	2.36	12.50	2.20	12.5	1.90
25	2.38	15.80	2.10	15.7	1.80
29	2.40	19.80	2.00	19.8	1.70
34	2.42				
39	2.44				
45	2.46				
51	2.48				
59	2.50				
67	2.52				
76	2.54				

Example: To calculate adj.SAR of water from

$$adj.SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}\left[1+(8.4-pHc)\right]$$

With report of water analysis
Na = 3.5 me/1
Ca+Mg = 1.0 me/1
Ca+Mg+Na = 4.5 me/1
CO_3+HCO_3 = 3.0 me/1
pHc=2.21+3.30+2.5 = 8.01 (from tables)

$$adj.SAR: \frac{3.5}{\sqrt{1/2}}\left[1+(8.4-8.01)\right] = 4.95\ (1+.39)$$

adj.SAR = 6.88

NOTE: Values of pHc above 8.4 indicate tendency to dissolve lime from soil through which the water moves; values below 8.4 indicate tendency to precipitate lime from waters applied.

(ref: L.V. Wilcox, U.S. Salinity Laboratory, mimeo Dec. 30, 1966)

TABLE 2

CROP TOLERANCE AND LEACHING REQUIREMENT OF MAJOR CROPS ROTATED WITH ALFALFA

Yield Decrement To Be Expected For Certain Crops Due To Salinity Of Irrigation Water When Common Surface Irrigation Methods Are Used[1/]

CROP	0%			10%			25%			50%		MAXIMUM
	ECe[2/]	ECw[2/]	LR[3/]	ECe	ECw	LR	ECe	ECw	LR	ECe	LR	ECdw[3/]
Barley	8	5.3	12%	12	8	18%	16	10.7	24%	18	27%	44
Sugarbeets	6.7[4/]	4.5	11%	10[4/]	7.7	16%	13	8.7	21%	16	26%	42
Cotton	6.7	4.5	11%	10	6.7	16%	12	8	19%	16	26%	42
Safflower	5.3	3.5	12.5%	8	5.3	19%	11	7.3	26%	14	28.5%	28
Wheat	4.7[4/]	3.1	8%	7[4/]	4.7	12%	10	6.7	17%	14	23%	40
Birdsfoot trefoil	4	2.7	10%	6	4	14%	8	5.3	19%	10	24%	28
Sorghum	4	2.7	7.5%	6	4	11%	9	6	17%	12	22%	36
Tomato	2.7	1.8	8%	4	2.7	12%	6.5	4.3	19.5%	8	24%	22
Corn	3.3	2.2	12%	5	3.3	18%	6	4	22%	7	26%	18
Cantaloupe	2.3	1.5	8%	3.5	2.3	12%	No	Data		No		-
Alfalfa	2	1.3	5%	3	2	7%	5	3.3	12%	8	19%	28
Lettuce	1.3	.9	5%	2	1.3	7%	3	2	11%	5	18%	18
Beans (Field)	1	.7	6%	1.5	1	8%	2	1.3	11%	3.5	19%	12

1/ From USDA-Ag. Inf. Bull. 283 and personal communication from Dr. Leon Bernstein, U.S. Salinity Laboratory, Riverside, California.

2/ ECe means electrical conductivity of saturation extract in millimhos per centimeter (mmho/cm): ECw means electrical conductivity of irrigation water (in mmho/cm.) LR = Leaching Requirement = $\frac{ECw \times 100}{ECdw}$. For an approximate conversion to TDS, mg/l, or ppm multiply mmho/cm by 640.

3/ ECdw is maximum concentration of salts that can occur in drainage water under crops due to ET. (ET means evapotranspiration). Use to calculate leaching requirement ($LR = EC_w/EC_w$) to maintain needed ECe in more active root area: Leaching Requirement (LR) means that fraction of the irrigation water that must be leached through the active root zone to control soil salinity at a specified level. At 100% efficiency, applied water (needed to satisfy ET + LR) is equal to ET/1-LR.

4/ Tolerance during germination (beets) or early seedling stage (wheat, barley) is limited to ECe = about 4 mmho/cm

NOTE: Conversion from ECw to ECe assumes that irrigation water salts increased 3 fold in salinity in becoming soil water salts (ECsw). This occurs in the more active part of ECw x 3 = ECsw; ECsw - 2 = ECe.

Salinity refers to the total concentration of dissolved salts in the water and is expressed as electrical conductivity in micromhos per centimeter. Frequently as in California the conductivity may be reported as millimhos per centimeter. The higher the salt content the greater the leaching requirements. As salt concentrates in the soil; water uptake is reduced and yield reduction occurs.

Alfalfa is considered moderately salt tolerant. Table 2. gives expected yield reduction for alfalfa and other crops commonly rotated with alfalfa. The table also gives EC values of the irrigation water, the associated EC value of the soil extract, the leaching requirement and the maximum EC of the drainage water. Crop tolerance and leaching requirement tables are important in prevention of salinity problems as it is much cheaper to avoid salinity problems than it is to correct a salt problem that need not have occured.

Permeability problems associated with water quality are those having a high proportion of sodium to calcium + magnesium. The sodium problem is evaluated through the adjusted SAR values. Low EC waters are also frequently associated with permeability problems. In some cases the addition of gypsum to the irrigation waters has been beneficial.

Toxicity problems are those from specific ions such as sodium, boron, chlorides etc. which may be absorbed by the plant in excess causing leaf burn. Additionally these elements may effect the nutrient balance within the plant.

Alfalfa is tolerant of high levels of exchangeable sodium, (about 40%) provided that the soil physical conditions have not been adversly effected. Boron (B) is an element which at a few parts per million in the irrigation water may cause retarded plant growth. Alfalfa however is one of the more tolerant plants. Boron should not be a problem to alfalfa where previous crops have not shown visable symptoms. However, when boron levels for alfalfa cause no problems, problems could be serious to more sensitive crops. Bicarbonate and chlorides at levels usually found in irrigation waters do not reduce alfalfa growth.

WATER MANAGEMENT

Water management is the application of the technical, practical and agronomic considerations of irrigating. Water management also recognize the fact that water allocations, priorities and scheduling may require adjustments depending upon the total farm management situation. Frequently irrigation water supplies are limited or are only available on a scheduled basis which then requires irrigations must be on a time schedule or must be modified as conditions warrant. Frequently other crops may receive priority for water resources. However, understanding the fundamentals assists one to make the correct decision. Water management must now also consider the management of tailwater, waste water, drainage water and percolation losses from the field.

The TECHNICAL aspects of good irrigation practices begin before planting when there are factors which can be properly considered. Proper land preparation for either flood or sprinklers is necessary. For sprinkler irrigation adequate surface drainage is necessary to eliminate areas where ponds or wet spots may develope. For border checks proper land grading to give good surface drainage is also important. Properly designed border checks make irrigation easier and more efficient. The length and width of the border depends upon the down slope and the cross slope of the field. The slope of the field depends upon the soil conditions and the crops to be grown.

Table 1 provides tentative standards for border widths, lengths and the unit flow for various soil types and slopes. Where longer lengths are used levee height and border width may have to be modified.

TABLE 1. TENTATIVE STANDARDS FOR BORDER WIDTHS, LENGTHS, AND UNIT FLOWS FOR VARIOUS SOIL TYPES AND SLOPES.

Soil Type	Slope	Strip Width	Check Length	Unit Flow Per Foot Width of Strip check	
	%	feet	feet	gpm	c.f.s
Sand	.2-.4	20-60	220-440	50-70	.11-.16
	.4-.6	20-40	220-330	45-50	.10-.11
	.6-1.0	20	220-330	25-40	.06-.09
Sandy Loam	.2-.4	30-80	660-1320	25-35	.06-.08
	.4-.6	30-40	660-1320	20-30	.04-.07
	.6-1.0	30	660-1320	10-20	.02-.04
Clay Loam	.2-.4	40-100	660-1320	15-20	.03-.04
	.4-.6	30-60	660-1320	10-15	.02-.03
	.6-1.0	30	660-1320	5-10	.01-.02
Clay	.2-.3	40-100	1320	10-20	.02-.04

The design of the irrigation system should be economical and still provide sufficient flexibility to allow adjustment of water application rates as needed and to prevent excessive losses.

Water requirements vary from area to area and region to region. Water requirements or the consumptive use in the cooler regions may be less than 0.10 inches per day to more than 0.40 inches per day in the hot and dry desert area. Specific consumptive use values are available at the Cooperative Extension Office. The irrigation system must be designed to be capable of meeting the maximum water needs and still provide sufficient down time for efficient harvest practices. Some variability in water use can be expected from variability due to soil conditions, vigor and fertility conditions. It is also true that it may require 5 times as much fertilizer to give the same response under dry conditions as it does under adequate moisture conditions.

Available water holding capacity of the soil is primarily estimated from texture. Generally the very coarse and the very heavy clay soils have lower available water capacities than do the medium textured soils. Generally only one half of the total moisture held is considered available. Soil structure is the arrangement of the soil particles and has a large effect on water holding capacity. Regardless of soil texture a compact, dense, hard, massive soil will not hold the estimated amount of water based on texture. When fields are found to have compact subsoils; ripping or subsoiling should be one of the primary practices during land preparation.

The soil water storage capacity of the soil refers to the amount of water which can be stored in the accumulated or total depth of the active root zone of the crop. The total capacity is important to avoid excessive applications which may cause water logging or to prevent deep percolation losses. When irrigation is done before the wilting point is reached most of the applied water will be available and useable by the plant. However when irrigations are infrequent or inadequate and the surface soil is allowed to dry below the wilting point then that portion of water which wets from some point less than wilting point to wilting point is unavailable to the plant. Then only that remaining amount above wilting point is available for plant use. Then proper irrigation means to time irrigation to gain maximum efficiency of the applied water.

Water intake caracteristics of most soils are such that the initial intake is most rapid and after a number of hours the rate has decreased significantly. There is a considerable variation among soils and the timing of irrigations period should be based on the length of time that it takes to apply the desired amount of water or when the additional hours the water is allowed to remain on the soil are ineffective and may cause more problems than the additional water is worth. Some soils having 1320 foot checks can be irrigated in less than 1 hour. Many border ckecks 2640 feet long have been adequately irrigated in 4 - 6 hours. Other soils may require as many as 24 hours. However, for alfalfa the longer the water remains on the soil after the major part of the soil water storage capacity has been satisfied the more problems associated with excess water there will be. Most generally irrigation should not exceed 12 hours. The convenience of 24 hours sets has little validity in irrigation practices.

The flow of water available frequently governs when and how a field shall be irrigated. This involves the PRACTICAL aspects of irrigation when it is necessary at times to irrigate earlier than desired because of the necessity of having to utilize the water source to the maximum or to sacrifice one crop for another. Irrigations may also be delayed because poor weather conditions may upset harvest schedules. Smaller heads of water generaly require narrower and shorter borders and possibly using greater slopes in the field.

Drainage from the soil surface and the internal drainage of the profile need to be considered. Surface drainage means eliminating low spots to avoid standing water in low areas. Surface drainage must now consider adequate disposition of tailwater Where tailwater can be adequately managed water application efficiency can be improved. Where tailwater is not controlled and does not drain rapidly, alfalfa stands at the tail end of the field will be effected. Where tailwater is controlled one can irrigate the field more rapidly with better water distribution. Internal drainage factors are concerned with prevention of excess water in the root zone because of slow infiltration rates in the subsoil. Restricting layers in the soil cause saturated zone to develope which frequently results in root rot development.

The AGRONOMIC aspects of irrigations deals primarily with the plants response to irrigation practices which should be tailored to the specific needs depending upon the existing conditions and not for convenience or personal preference. The amount of water to apply at an irrigation depends upon the characteristic of the soil. The amount of water the soil holds per foot of depth, the depth to which the crop is to be irrigated and the amount of water necessary to replenish that used by the crop are important considerations in irrigation. Irrigate only when necessary and it should not take place before the plants have had an opportunity to use most of the available moisture.

An idea to keep in mind is to have more frequent light irrigations by using a larger head of water for quick irrigations. Penetration will not be as deep but the excess or surface water can move down through the soil.

To get more even distribution during an irrigation it is necessary to begin with as large a head as possible that is non-errosive, later cutting back the flow to allow only a minimum amount of tailwater, and continuing as long as necessary for the desired irrigation.

A strong, healthy root system is generally not severely injured by one irrigation, though sometimes it appears to be. Stand depletion problems are a result of the accumulated effects of previous poor irrigation practices. Improper irrigation practices create a favorable environment of soil organisms which attack and destroy the root system, the combination of damaged roots and root rot organisms greatly weaken the plant.

A newly cut alfalfa field will require much less water than at any other time. As the plants recover and growth increases the plants will continually require larger and larger amounts of water. The length of time between irrigation is important. The interval in days between the first irrigation and the second should be greater than the interval between the second irrigation and the time of cutting. The same is true when irrigating three times per cutting.

Moisture condition at harvest time should be dry enough to prevent soil compaction from harvesting equipment and still allow regrowth to become established. Five to six days should elapse before irrigating after cutting to allow partial recovery of the plants. Recovery of the plants reduces the susceptibility of the plants to scald damage

Testing the pump where water is obtained from wells is another important management practice which allows better management of water. When a pump is adjusted and serviced to operate at near maximum efficiency irrigations are accomplished in less time, irrigation efficiency is improved, less labor is used, and pumping costs per acre foot are reduced. With information developed during the pump test one can determine approximately how many acre feet of water have peen pumped. Knowing the acreage the water has been delivered to allows one to evaluate the overall irrigation program.

WATER MEASUREMENT

The measurement of the amount of water applied from either sprinkler or surface flood system is the first approximation on how well we have irrigated. When we know how much we have applied we can then estimate how frequently we must irrigate and whether or not we have over irrigated or under irrigated.

When water delivery is in gpm or cfs the following formula allows the estimation of the applied water in acre-inches/acre.

$$\frac{\text{gpm x hrs}}{\text{450 x acres}} = \quad \text{acre-inches/acre}$$

$$\frac{\text{cfs x hrs}}{\text{acres}} = \quad \text{Acre-inches/acre}$$

The evaluation of how much water remains in the soil at any time before or after an irrigation can be accomplished by many methods, instruments and proceedures. Methods vary as to their cost, operation, effectiveness, advantages and disadvantages. The use of soil tubes or the shovel are the minimum one should use.

The following methods are not recommended at the present time: gravimetric, Gamma-ray, Neutron probe, suction table, pressure equipment, psychrometer, freezing point, penetrometer, electrical capacitance, electrothermal and porous absorbers.

The two methods which are acceptable and useful with their appropriate limitations are tensiometers and electrical resistance (gypsum) blocks. Growers have generally not accepted the use of either tensiometers or gypsum block in alfalfa production while they have for other crops. Frequently the grower must irrigate on a planned schedule and the servicing, protection and interpretation of the instruments is time consumming.

Tensiometers measuring soil suction are used for the moist soil conditions and can not be used on the dry soils. They provide repeated readings at the same locations. They are quick, accurate, but are temperature sensitive, require field servicing and crops may be trampled.

Gypsum blocks are also used to measure soil suction and operate in the drier soil water range on non-saline soils. They are placed for repeated measurement. They should not be used for saline soils or where the soils are kept in the wetter range. They are generally inexpensive, and like tensiometers some trampling of the crop occurs.

Both of the instruments have proved to be very useful in solving irrigation problems and evaluating irrigation practices. Since tensiometers are used in the low suction range they are more useful in the sandy and medium textured soils and the gypsum blocks work in the upper range of soil moisture and are more useful in the heavier textured soils. However they can be used to supplement each other.

Since alfalfa grows best in the low suction range, tensiometers should be the preferred instrument. Tensiometers also have the advantage that they can be used to evaluate water tables or excessive soil moisture condtions.