

Water-Soil-Plant Relations

soil moisture-plant growth relations are influenced by many factors including soil type, plant root systems and weather

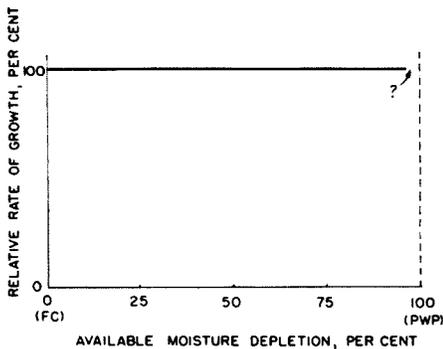
Robert M. Hagan

With irrigation—and where necessary, with drainage—the farmer can exercise greater control over soil moisture than over any of the other soil physical factors.

Water held in the larger pores in most good agricultural soils drains away within a few days after an irrigation or heavy rain leaving the soil at a moisture content called field capacity. Plants growing on the soil will extract water, and if none is added plants will ultimately wilt. The moisture content at which that occurs is the wilting point. The water held by a soil between field capacity and the wilting point is called the available water. Various soils retain different amounts of water at field capacity and wilting point; therefore, they have different water capacities.

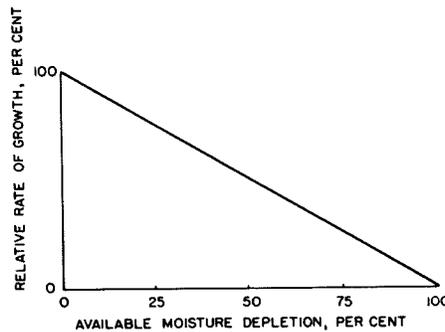
Existing viewpoints on soil moisture-plant growth relations and the probable influence of plant, soil, weather, and several miscellaneous factors on these relations are illustrated by a series of schematic diagrams. Most of these diagrams illustrate plant growth responses as available soil moisture is depleted within one irrigation cycle.

Under some conditions plants can apparently obtain a supply of water with equal facility between field capacity and the permanent wilting percentage as illustrated by the first diagram. This represents the view that the rate of plant

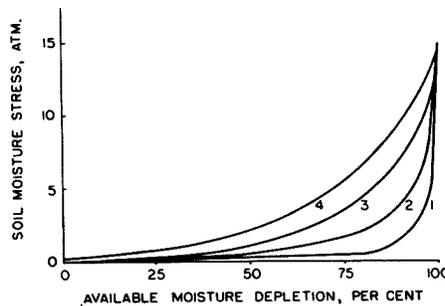


growth is not diminished over the available range or, that no measurable increases in rate of growth are obtained by irrigating until the soil moisture falls to near the wilting point. The question mark indicates some uncertainty as to just when some plant response may be detected near the wilting point.

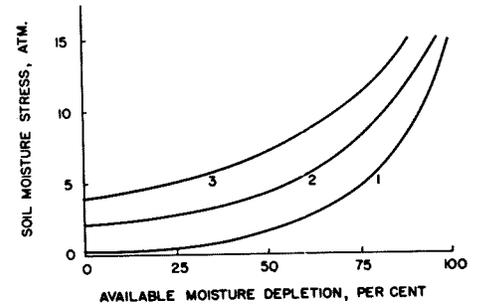
On the other hand, it is often maintained that plant growth diminishes progressively as the soil moisture content falls below field capacity with growth ceasing at the wilting point—as illustrated in the second diagram—but this more water, more growth idea finds little support among research workers.



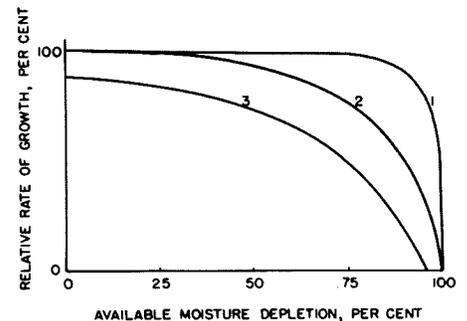
The availability of soil moisture is now frequently described in terms of soil moisture tension, which is dependent upon surface forces, and in terms of total soil moisture stress, which includes surface and other forces arising from the presence of solutes in the soil solution. The following diagram illustrates the increase in soil moisture stress in four nonsaline soils of different textures—sands to clays—as the available moisture is depleted from field capacity to the wilting point.



Excess salts in saline soils appear to influence plant growth in several ways including possibly an effect on water availability. Moisture content-soil moisture stress relations for a given soil to which increasing amounts of soluble salts had been added are given in the following graph.



The theory that plant growth is a function of soil moisture stress is next expressed diagrammatically. If such a relationship exists, little retardation in growth on the nonsaline sandy soil would be expected until nearly all the available water had been depleted—curve 1—but on the nonsaline clay soil illustrated some slowing of growth should occur after about 50% depletion—curve 2. On the saline soil illustrated—curve 3—a reduced growth rate would be expected even at moisture contents near field capacity, and growth would be expected to decline appreciably even in the upper half of the available moisture range.



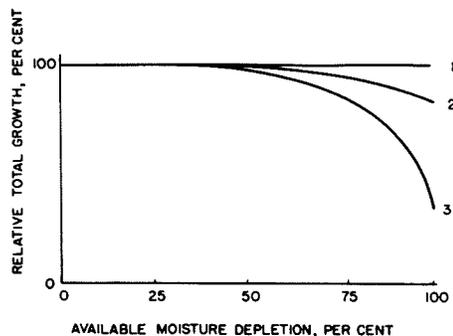
So far consideration has been confined to growth rates within one irrigation cycle. If moisture is equally available for plant growth over the entire available range during each irrigation cycle, then total growth over a period of such cycles will be independent of the level of moisture depletion permitted before irrigation within each cycle. This relationship is indicated by curve 1 of the next diagram. If, on the other hand, growth rates are related to soil moisture stress, then total growth over a period during which

Continued on next page

WATER-SOIL-PLANT

Continued from preceding page

the stress varies may be related to some average stress condition—curve 2—where the shape of the curve will depend on the soil moisture stress-moisture content curve for that particular soil. On the other hand, some field studies suggest that yields are related to maximum

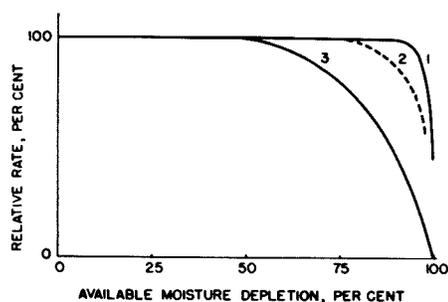


stress prevailing prior to irrigation. In other words, high moisture stress values, though present for only a brief time interval, may have exaggerated effect on plant responses—curve 3. Considerable experimental support can be found for each of these generalized relations. This situation indicates that moisture-growth relationships must be greatly influenced by the interplay of other factors which independently affect plant growth.

Plant Factors

Several different aspects of plant growth—such as elongation of plant organs, increase in fresh or dry weight, and vegetative versus reproductive development—are easily recognized. These commonplace processes are resultants of intricate combinations of many physiological processes which are probably not all equally affected by increasing soil moisture stress and an accompanying change in the internal balance of cells and tissues. Thus it is not surprising that various measurable aspects of growth do not respond in the same manner to moisture stress.

Data from studies on ladino clover illustrate this point. Some plant functions such as photosynthesis and respiration



are relatively insensitive to moisture stress—curve 1. Dry weight production may be more sensitive—curve 2. Fresh weight yield and elongation of plant organs appear to be still more sensitive to moisture stress—curve 3.

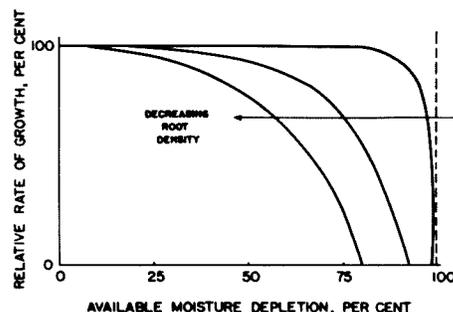
As plants are subjected to increasing moisture stress, appreciable shifts in the relative abundance of a variety of chemical constituents may occur in some plants. The percentage of sugar in cane and beets is raised by moisture stress. In tobacco increasing stress is reported to lower the sugar content and increase the percentage of nicotine and nitrogen in cured leaves. Thus the economic value of a crop may be influenced appreciably by moisture stress particularly during the period of maturation. Differences noted in the response of various growth processes to moisture stress point the way to the possibilities of so controlling the soil moisture stress through the growing season as to favor the production of that constituent or plant organ for which the plant is grown.

The effects of given soil moisture stress conditions on crops are often dependent upon the state of plant growth. Corn appears to be particularly sensitive to moisture stress during the tasseling period. Vegetative vigor is not necessarily associated with a comparable degree of productivity, as in the case of cotton where yields may be relatively higher on small plants than on tall or rank plants.

Another plant factor of extreme importance in determining the relation between measurable soil moisture stress and plant growth is the nature of the root system. Different interpretations of root development and of moisture conditions within the soil penetrated by roots contribute to the existence of contradictory views on water-soil-plant relations. Under favorable soil and growing conditions, most perennial crops develop well-branched root systems which thoroughly permeate the soil to a depth characteristic of the plant. Below this depth, the spatial density of absorbing roots diminishes until so few remain that moisture extraction can not be detected.

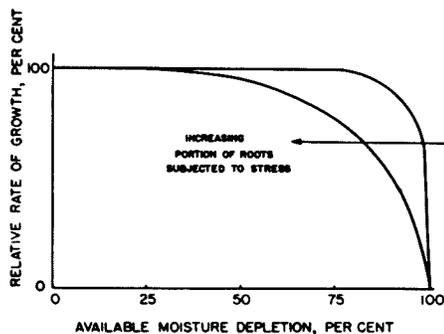
Moisture conditions within the expanding root system of an annual crop are even more complicated. In the seedling state, only a taproot or a few branched roots penetrate the soil. Some annuals rapidly develop a well-branched root system which permeates an ever-enlarging soil volume. Thus if the soil has been previously wet to field capacity through a considerable depth, these growing roots continuously come into contact with additional supplies of available water at low tensions. If the roots are well-branched and grow rapidly enough, they may contact new supplies of readily available water with sufficient rapidity to replace the water lost from

the leaves by transpiration. Because of rapid root growth, a crop such as watermelon on a deep alluvial soil may not respond to irrigation even though a relatively high soil moisture stress may develop within an ever-increasing soil volume. Other annuals send out a few widely spaced roots which leave large volumes of unexplored soil between roots particularly in the early stages of growth. Under such conditions soil moisture samples or even moisture indicating devices may give quite a false picture of moisture conditions at the root surface. Crops with sparse roots will respond to irrigations although the measured soil moisture stress may be quite low. As indicated in the following diagram, the sparser the roots the greater the likelihood that growth will be retarded by delaying irrigation. Very similar varieties of beans have shown different responses to irrigations, which are related to differences in their root development. Thus the fraction of the available moisture range which can be utilized before growth is checked will vary with root density.



Until methods are developed to measure the moisture stress experienced by plants, it apparently will be necessary in the case of sparse-rooted crops to establish some rather arbitrary moisture depletion limits which unfortunately will depend on the stage of growth, growing conditions, and upon such other factors as soil and weather.

Where some roots extend beyond the bulk of the root system and absorb water against low soil moisture stresses, they may mask the effects of relatively high soil moisture stresses occurring over the remaining part of the root system. When most of the roots are confined to a given volume of soil and few roots extend out into relatively moist soil, the crop may be expected to be relatively sensitive to depletion of the available moisture. However, when a considerable number of roots extend into moist soil, depletion of the available moisture from the major part of the root zone may have relatively little influence on growth as indicated schematically at the top of the next column. The presence of an unknown fraction of the total absorbing roots extending out into relatively moist soil makes



it very difficult to evaluate the actual soil moisture stress to which the plant is subjected. Plants confined to containers or shallow soils may be expected to be quite sensitive to depletion of the available soil moisture.

Soil Factors

Any soil factor which affects root density or depth can be expected to influence the response of the crop to irrigation. Mechanical impedance, slow water penetration and poor internal drainage, and deficient aeration frequently are responsible for sparse and shallow roots. Soil structure, texture, and depth determine the total capacity of the soil for storing available water for plant growth. The total available moisture capacity within the root zone and the moisture-release characteristics of the soil are both important factors determining the rate of change in soil moisture tension or stress. Deep-rooted crops on deep soils usually show smaller responses to irrigations than shallower-rooted crops on the same soil. Crops growing on a soil in which 75%–85% of the available water is released at tensions below one atmosphere may be expected to show a smaller response to irrigations at a given moisture depletion level than the same crops growing on a soil in which less than 50% is released at such low tensions. The rate at which water can move to the absorbing root surface may play an important part in water-soil-plant relations.

A stable water table in the lower portion of the normal root zone of a crop may supply a considerable portion of the water absorbed by the roots and make the plants less responsive to moisture changes in the soil above the capillary fringe. On the other hand, a fluctuating water table may increase crop responses to early irrigation by restricting live roots to a shallow depth. Salinity may affect soil moisture-plant growth relations by decreasing moisture availability through increased soil moisture stress, by interfering with root growth and absorption through toxicity reactions, and by contributing to poor soil structure, which in turn influences infil-

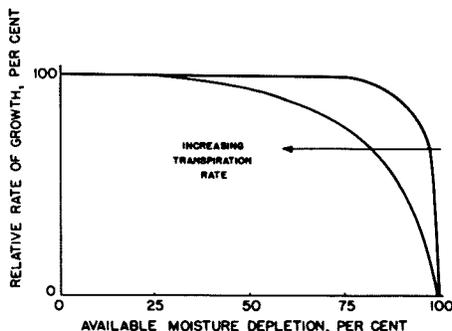
tration, drainage, aeration, and root growth. Soil-borne plant diseases and nematodes, by reducing root surface, may cause crops to respond favorably to irrigations at seemingly very low moisture stress levels. Soil temperature also affects the rate of root growth and root distribution with depth.

The fertility status of the soil and possibly the depth distribution of some essential element may also determine the growth response of crops to irrigations at various moisture depletion levels. At low nitrogen levels, infrequent irrigations may produce as high or perhaps even higher yields than more frequent irrigations which cause some loss of limited nitrogen by leaching. However, when ample nitrogen is applied, this same crop may respond very favorably to the more frequent irrigation schedule. In soils where the available supply of some essential element is confined to the top soil, the drying out of the upper portion of the root zone may seriously retard plant growth even though the plant may still be adequately supplied with water from a less fertile subsoil. Fertility responses have complicated the interpretation of many soil moisture versus plant growth experiments.

Weather Factors

Weather conditions—particularly light and temperature—may so influence the growth characteristics of the shoot and root as to affect soil moisture-growth relations. Late-planted sugar beets which must develop roots during hot dry weather may fail to develop as dense or deep a root system as early seeded beets. Such beets are much more sensitive to depletion of available moisture than are the deep rooted beets planted early in the year. The length of the crop season before fall rains or frost may at least partially determine whether harvestable yields will be affected by imposing different soil moisture stress levels during the growing period.

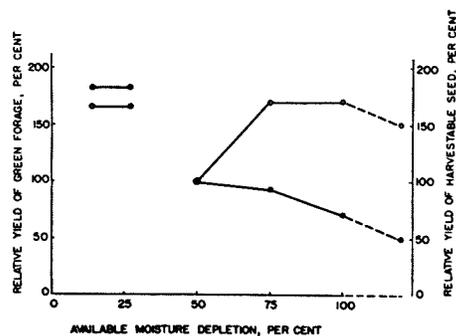
Meteorological factors—light, temperature, humidity and wind—control the rate of water loss by transpiration from plant leaves and evaporation from the soil surface. Plant growth is probably



dependent upon plant turgor, whose relation to soil moisture stress for different rates of transpiration needs to be explored. It can be reasoned that an increased rate of transpiration would lower the plant turgor corresponding to any given soil moisture stress. This would have the effect of causing growth to diminish at higher moisture levels as illustrated below. Much more work on this point is needed.

Miscellaneous Factors

Problems associated with insect control or harvesting may at times influence the apparent effects of soil moisture conditions on crop yields. The following study of forage and seed production by ladino clover provides an interesting example.



Increased dryness reduced forage yields but increased the harvestable yield of seed. The total seed actually produced by the clover also diminished with increased stress, but the higher humidity associated with the wettest treatment caused such a serious preharvest loss of newly produced seed as to reduce the harvestable yields at the end of the season below those on the drier treatments. Some types of harvesting problems may affect the results of soil moisture-plant growth experiments more frequently than is realized.

Mention has been made of a sizable number of soil, plant, weather, and other miscellaneous factors which may influence the effects of various moisture depletion levels on plant growth or yield of some specific organ or constituent. When viewed against this background, it is not at all surprising that conflicting results have been obtained even in irrigation experiments involving some given crop. This discussion emphasizes the probable impossibility of finding any one generally applicable relation between crop yields and soil moisture depletion or soil moisture stress, at least as measured by our present methods.

Present information, meager though it is in many respects, may allow us to make some fairly accurate predictions

Concluded on next page

WATER-SOIL-PLANT

Continued from preceding page

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

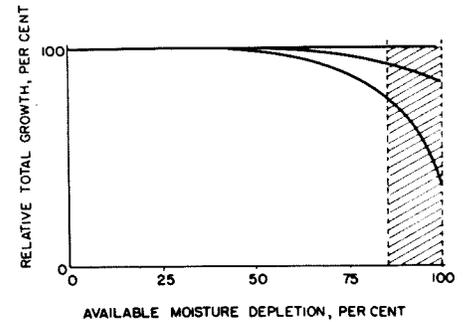
pay for the added cost of water and labor. The following practical considerations all suggest the desirability of using irrigation water sparingly: maximum use of limited water supply, water and nutrient losses caused by deep percolation, danger of developing a drainage problem through overirrigation, 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 prac-

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



tical 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.

Robert M. Hagan is Associate Professor of Irrigation, University of California, Davis.

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.

QUALITY

Continued from page 8

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.

Continued on page 31