

Irrigation in Arizona

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Dedicated to the man with the shovel

FOREWORD

The purpose of irrigation is to make the soil a more favorable feeding place for plant roots. Good irrigation practice, therefore, must take into account the needs of plants, the parts played by roots in supplying those needs, and the soil conditions necessary to enable the roots to feed to the best advantage.

In the following pages the authors will not attempt to present new information, but only to bring together and organize accepted facts, that these may be in more convenient form for field use.

IRRIGATING IN ARIZONA

BY E. S. TURVILLE AND DONALD L. HITCH

INTRODUCTION

The irrigator should know what happens to water after it passes beneath the surface

1. Irrigation would be much easier to plan if one could see below the soil surface and note what is taking place there: how fast the water moves downward; how far it goes; where it goes; what happens when it reaches a hard soil layer; how fast and how far it moves sideways from the furrow; why it sometimes moves farther than at other times; when it moves back towards the surface and when it does not; how it is stored in the soil; how the soil dries out; and many other underground water movements which together make for success or failure of an irrigation plan.

The irrigator should know root character and habits

2. Irrigation water is important only as it creates a more favorable feeding place for plant roots. The irrigator, therefore, should know how root systems behave; how far they go down into the ground; where they stop and why; how far they reach out from each side of the plant; what happens when they hit dry soil, hardpan, or a strongly alkaline streak; how they use the soil water; what percentage of it they absorb, and what happens when they have used it all. Do roots grow to water or does the water move to the roots? Is the whole root zone full of roots, or are these merely scattered about? Do they follow a pattern?

This publication presents principles of irrigation, not rules

3. Research men have spent much effort digging through the soil to gain answers to soil-moisture movements and root habits. They have valuable information although many questions are still unanswered. It will be the purpose of this publication to present, from the answers the research men have given us, a picture of conditions below the soil surface and to suggest the use of this information in irrigation practice. *It is not the intention to offer detailed plans for the irrigation of crops.* Conditions are varied and set rules of irrigation are difficult to make. It is the belief of the authors that irrigators, knowing the soil and water forces operating and the rooting habits of plants, can work out the rules best suited to their own soil, water, and crop situations.

No attempt to discuss minute scientific detail

4. The intention of the publication is to present material in such a way that it can be used in the field. The statements made will be

true for practical purposes, but no attempt will be made to discuss minute scientific detail. Thus, when it is said that "soil moisture below the field-carrying capacity is stationary," it means that such is the case as far as the irrigator is concerned. The scientist finds that the movement of moisture in very small amounts and through very short distances never ceases.

Only average Arizona soils considered

5. The reader is cautioned to note that this publication deals only with Arizona soil, water, and climatic conditions, and that many of the statements made would not apply to the humid areas or even to some unusual conditions within the state.

Certain soil, water, and root characters are peculiar to Arizona and other like areas

6. A few of the plant-growth conditions of the semiarid regions of the Southwest are:

1. Low humidity throughout most of the growing season.
2. Small annual rainfall over most of its area.
3. High temperatures during the summer growing season in the larger agricultural areas.
4. A trend toward soil alkalinity rather than acidity.
5. High mineral- and low organic-matter content in most soils.
6. Low soil aggregation (crumb structure) common in the heavier soils.
7. Soil usually deep and relatively without marked tight or toxic layers in its root zone.
8. Soils and waters that sometimes carry an excess of salts.
9. A deep plant rooting system in most soils.

Soil characters are changed by cultural treatments

7. Another word of caution is that soils are not constant quantities. For instance, the heavy clays and silts, normally more or less compact, "cheesy" masses, show a good crumb structure when mixed with large amounts of organic matter—they "handle" much like the loams. The coarse sands, treated with organic matter and irrigated with silty water, acquire improved water-holding characters. However, the soils are here described as they are usually found.

All these factors must be kept in mind when an irrigation plan for Arizona soils is set up, and allowances must be made for differences between such plans and those recommended to irrigators in other sections of the country.

Knowledge of soil facts reduces work of irrigator

8. Since the irrigator deals directly with water and soils and only indirectly with plant roots, this study begins with a discussion of soils, their character, and why and how they influence irrigation practice. It is of course possible to learn such facts entirely by the

TABLE I.—IRRIGATED AREAS IN ARIZONA (See MAP Page 6.)

No.	Name of Area	Average elevation	Mean annual temperature (degrees)	Average annual precipitation (inches)
Apache County				
1	Alpine	8,000	43.6	22.82
2	Concho	5,800	.....	.....
3	Nutriso	8,000	.....	.....
4	Springerville	6,980	46.6	11.79
5	St. Johns.....	5,650	52.3	12.17
Cochise County				
6	Elfrida	4,100	62.5	13.80
7	Hereford	4,200	.....	11.99
8	Pomerene	3,500	64.2	11.07
9	St. David.....	3,600	.....	11.99
10	Stewart	4,200	59.6	11.99
Coconino County				
11	Fredonia	5,000	52.1	15.75
12	Sedona	4,200	.....	.....
Gila County				
13	Tonto Creek.....	2,400	.....	21.87
14	Pinal Creek.....	.....	62.6	16.10
Graham County				
15	Safford	2,900	62.8	9.73
Greenlee County				
16	Duncan-Upper Gila	3,640	58.9	11.09
Maricopa County				
17	Gila Bend.....	737	72.2	5.91
18	Queen Creek.....	1,400	.....	.....
19	Salt River Valley	1,100	68.2	7.78
Navajo County				
20	Holbrook	5,070	54.6	9.33
21	Joseph City.....	.....	.....	.....
22	Lakeside	7,000	47.2	22.44
23	Pinetop .....	.....	.....	.....
24	Sholow	6,300	.....	17.64
25	Snowflake	5,640	51.4	12.98
26	Winslow	4,880	54.9	8.79
27	Woodruff .....	.....	.....	.....
Mohave County				
28	Big Sandy.....	1,950	.....	10.50
Pima County				
29	Continental	2,800	.....	12.8
30	Marana	2,000	.....	.....
31	Sahuarita	2,400	.....	.....
32	Tucson	2,400	67.2	11.50
Pinal County				
33	Eloy	1,500	71.0	9.60
34	Sacaton	1,300	58.4	9.63
35	San Carlos (Coolidge-Casa Grande)	1,400	68.7	9.39
36	Stanfield	1,300	71.0	8.30
Yavapai County				
37	Little Chino.....	4,600	.....	14.36
38	Camp Verde.....	3,100	.....	13.12
39	Cornville	3,300	.....	12.23
40	Cottonwood	3,200	.....	.....
41	Big Chino.....	4,600	.....	.....
Yuma County				
42	North and South Gila.....	144	67.8	4.00
43	Parker	385	69.8	5.16
44	Roll-Wellton	225	70.7	4.63
45	Yuma Mesa.....	200	72.2	3.82
46	Yuma Valley.....	110	69.4	3.74

MAP on next page shows location of IRRIGATED AREAS in Arizona.

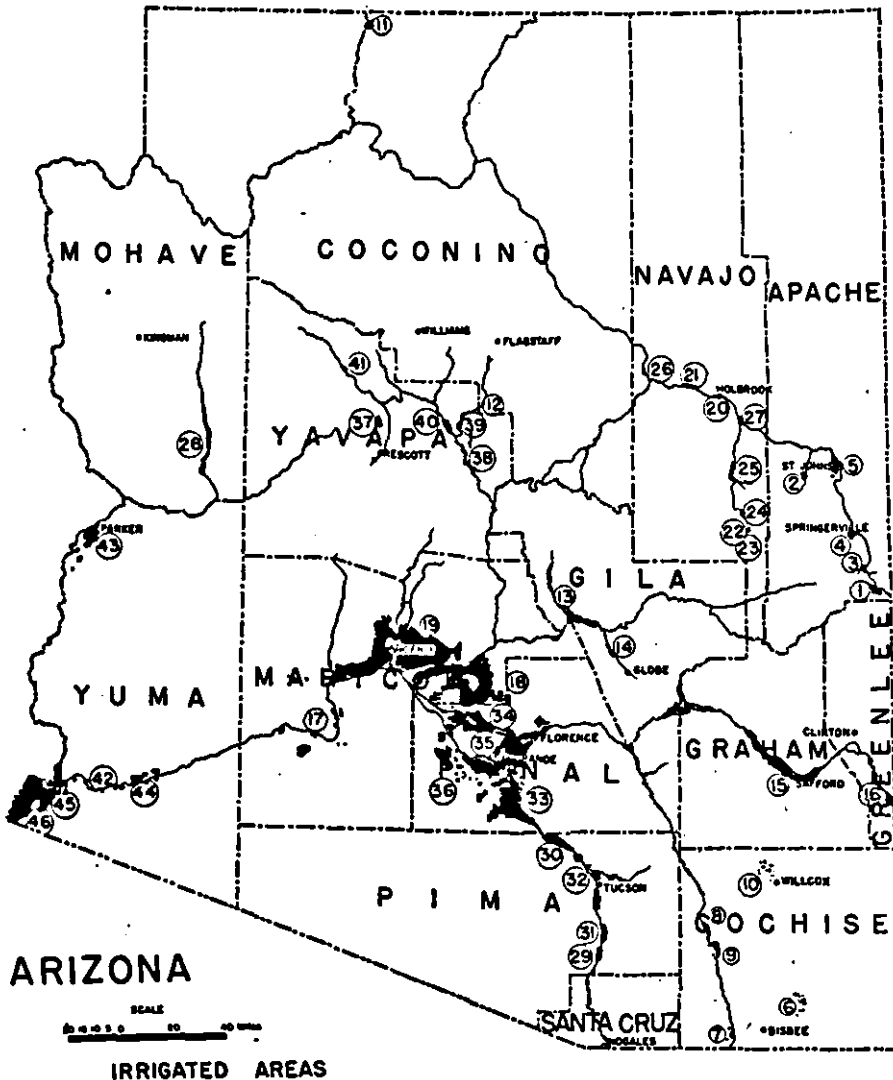


Figure 1.

trial and error method, but this requires many trials and much digging to find results. Some of this work has to be done, but it may be reduced by using available knowledge of what to expect, considering the class of soil, its water-holding ability, and the manner in which water moves through it.

This publication outlines the physical properties of soil, the movement of water through soils, and the chemistry of soils as they affect irrigation practices.

THE CHARACTER OF SOIL AS IT AFFECTS IRRIGATION PRACTICE

BY H. V. SMITH*

Soil is decayed rock, plant, and animal material

9. Soil is a very complex natural body which covers the surface of the earth. It consists of broken-down and decayed rocks (mineral matter) and decaying or decayed plant and animal material (organic matter).

Soil particles differ in size (soil classes)

10. At the outset it must be recognized that some soils are made up of large particles (sands), medium-sized particles (silt), and very fine particles (clay). A fourth class is a mixture of fine and coarse particles and is called loam.

Size of soil particles affects rate of water penetration

11. It is common knowledge that when marbles are placed in a cup, larger air spaces result than when buckshot is used. When bird shot is substituted for the larger particles, still smaller air spaces are formed.

The penetration of water through the marble spaces would be rapid, through those of the buckshot less rapid, and through the bird shot still slower. These simple facts illustrate the first factor in water penetration; that is, the effect of the size of particles in influencing the rate of water penetration into and through soils: the larger the particles, the more rapid the penetration.

Some soil particles unite into clusters; others do not

12. The second penetration factor deals with a quality of some soil factors which marbles and lead shot do not possess. It is a quality which results in the uniting of particles into groups, variously called aggregates, granules, or crumbs. Only the very small silt and clay particles have this power of uniting. When combined, these new soil units act much as larger particles: they increase the size of the air spaces and thus speed up water penetration. When silt and clay particles do not combine into crumbs but remain as separates, they are said to be dispersed or deflocculated. The tendency of soils to form crumbs is a property of clays more than of silts. Sands or gravels do not aggregate (combine) unless cemented by finer particles.

Penetration slow through silt and clay soils except when granulated

13. If a soil contains much fine clay, water penetration is slow unless the clay is well granulated. Fine clays have the property

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of swelling when wetted, further reducing the size of the air spaces in the soil and thus slowing down water penetration.

In the dispersed state, the small separate soil particles pack closely together, thus reducing the rate of penetration of both air and water. Furthermore, these tiny particles hold their water so tightly that plant roots absorb it with difficulty. The practical application of these facts in farm practice is discussed throughout this publication.

Crumb structure essential for good tillage of heavy soils

14. Since sands do not aggregate into granules they are said to have a single-grained structure, in contrast to the compound structure of a granulated soil of heavier texture (finer particles). If loams and clays do not have good crumb structure (a union of particles) they are said to be partially or completely dispersed. Such soils are hard and cloddy and have a generally poor physical condition. This is the case when the crumbs break apart because of unfavorable chemical conditions, *lack of sufficient organic matter*, or improper tillage. A dispersed soil will cost more to till than one which is granulated.

Pure sands inefficient farm soils

15. Pure sands are not efficient, all-purpose farm soils. They take water rapidly but do not hold it well. They tend to be droughty and leachy and to need special irrigation treatment, especially in the matter of frequency of irrigations and fertilizations.

Heavy soils require special care in handling

16. Clays, unless in good physical condition (granular), have features equally as undesirable as those found in sands. They require careful attention at irrigation time to make certain the water has penetrated to the full depth of the root zone. Tillage must be limited to the time when the soil has the right moisture content. If tilled when too wet,¹ the soil will puddle. A puddled soil prevents the normal entrance of both air and water.

Loam soils have desirable tillage qualities

17. The loam soils—those which consist of medium-sized particles or a mixture of large and small particles in proper proportion—have the most desirable physical conditions, and these conditions can be maintained much more easily than in either a sand or a clay soil.

Soil survey maps valuable sources of information

18. Since no two soils are exactly alike in their physical or chemical make-up or in their behavior toward irrigation and

¹Soils puddle only when they are at or near their field-holding capacity, and this latter moisture content is somewhat above good working condition.

cropping, a soil survey map and report should be consulted where available. This report contains information dealing with the more important characters of each soil, such as texture (size of soil particles), structure (arrangement of soil particles), hardpan, alkali concentrations, slope, etc. Together, these determine the type of soil. All these factors must be considered in planning an efficient scheme of irrigation or soil management. They may also be used as a guide in choosing farm lands.

Good physical condition of soils needed for best crop results

19. If the soil can be kept in good physical condition, fewer chemical and bacteriological problems will occur than when it is allowed to become puddled or otherwise physically unfit. For emphasis, it must be repeated that organic matter is a major factor in retaining good physical condition and favorable penetration qualities.

HOW MOISTURE MOVES THROUGH SOILS

By H. V. SMITH

Gravity and capillarity pull water through soil pores

20. We are all familiar with gravity—the force which makes objects fall—and with capillarity, usually described as the force causing liquids to “creep” in any direction. The movement of oil upward through a lampwick is an example of capillarity. It is the force which produces subbing in any direction in a soil. As previously explained, soil is made up of soil particles and soil crumbs (groups of soil particles) arranged in such way that air spaces or pores are formed where particles and crumbs fail to touch one another. It is through these pores that water penetrates into the soil, and the chief forces moving it are gravity and capillarity. Other forces operating are adhesion, cohesion, and surface tension. Adhesion is the force holding unlike particles together, such as soil particles and water. Cohesion holds like particles, such as soil particles themselves. With surface tension we need not here be concerned.

Film water remains after gravity water removed

21. If one should plunge a dry stick into water and then withdraw it, the excess (gravitational) water would drip off, leaving only a thin film on the stick. This remaining portion is usually called film water. When a soil is irrigated, most of the water seeps down through the pore spaces in the soil to lower levels, much as it drained from the wet stick, but the soil, like the stick, retains some film water surrounding the particles and crumbs. It is this film water with which the plant is chiefly concerned.

Immediately following an irrigation all the soil air spaces or pores are full of water, as is shown in Figure 2. Within a few



Figure 2. — Particles and water films in a saturated soil.

days, however, the excess has moved downward, leaving only the film water covering the soil particles and crumbs and that which is wedged into the angles between them. The pore spaces become filled with air as the excess water moves lower.

Water films reduced in thickness as water is removed from soil

22. When the last bit of gravitational water has leached away, the soil particles and crumbs are surrounded by relatively thick water films. As time goes on, under normal cropping conditions the films are reduced in thickness, the soil becomes drier, and less water is available to plants. This film-reducing process plays an important part in soil-water-plant relationships and in the movement of water through the soil.

Attraction of soil particles for water may be compared to attraction of magnets for iron

23. The soil particles and crumbs may be said to act as small magnets in holding the water films. The force with which the soil particles attract the water depends mainly upon the thickness of the film. A thin water film is held very tightly by its soil particle, a thick film rather loosely. Gravity, when still effective, pulls the water of the outer portion of the film lower into the soil until the gravitational pull is equaled by the attractive power of the soil particle for its water film. At this moisture content the soil is said to be at the field-holding capacity, as illustrated in Figure 3, and for practical purposes water movement ceases. From this point on, the moisture in the soil below the surface 8 or 10 inches is said to be stationary and is reduced only by root absorption.

Capillarity causes lateral as well as vertical movement of water

24. As long as gravity water remains in the soil there is a lateral or horizontal movement. The drier soil particles, having thinner water films, tend to pull water away from the adjacent soil particles having thicker films. This film movement of water from wet to dry soils is caused by the force of capillary attraction and is usually called subbing.

Not only does this force move the water horizontally but it also moves it upward, downward, or in any direction to points where the water films are thinner. But note carefully: capillary water movement in practical amounts occurs only when there is gravity water present; that is, when the soil moisture content is above the field-holding capacity, when there is still an excess of water in the soil.

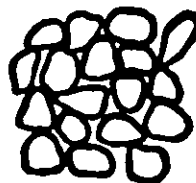


Figure 3. — Particles and water films in a soil at field-holding capacity.

Soil-moisture losses slight from depths greater than 6 to 10 inches if soil uncropped

25. When the forces of capillarity and gravity have acted together on the water in the soil, a point is reached where there is, for practical purposes, no further movement of soil water in any direction. Below a depth of 6 to 10 inches from the surface of a soil in which plants are not growing, the amount of water present remains almost constant over a period of months or even years; it is stored water.

Roots can reduce soil water to about one half field-holding capacity

26. In a soil supporting plant growth, the conditions which affect soil moisture are entirely different from those existing where no crop is growing. Here the absorption of water by roots becomes an active force competing with all the other forces above described which either hold or move the water. This loss of soil water by root absorption causes the water films surrounding the soil particles, as shown in Figure 3, to lose about half their volume and to appear as in Figure 4.

Roots cannot absorb water when soil moisture is below wilting point

27. As illustrated in Figure 4, the roots have taken all the water they are able to pull away from the soil particles, and the soil is said to be at the wilting point, or more properly, within the wilting-point range, since there is some variation in this measurement. It must be remembered that the moisture content of the soil, as illustrated in Figure 4—wilting point—is still about half of that present under the conditions illustrated in Figure 3—field-holding capacity—but because the water films are now so thin the particles hold them too tightly for the roots to absorb more water.

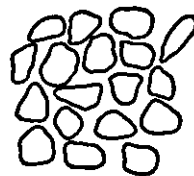


Figure 4. — Particles and water films at wilting point.

Only heat and dry air reduce soil moisture below wilting point

28. The water remaining in the soil at the wilting point (Fig. 4) is not removed except by exposure to the heat of sun or air, and even then not all of it can be removed.

Irrigation should refill working root zone from wilting point to field-holding capacity

29. In practice, the irrigator seldom plans to wait until the soil reaches the wilting point (Fig. 4) before applying more water. The irrigation should be sufficient to refill the soil of the working root zone to the field-holding capacity, or to the condition shown

in Figure 3. The amount of water needed for this refill will of course vary with the class of soil (as illustrated in Section 49) and the moisture content of the soil immediately before irrigation.

Coarseness or fineness of soils determines holding capacity

30. Since the size of the pore spaces varies with the size of the soil particles, the rate of water penetration is greater through a coarse-textured soil than through one of fine texture. However, the fact should be recalled that not only does each soil particle or grain carry its own water film, but the same is true of groups of particles (crumbs or aggregates). If, therefore, a large number of aggregates are present the effect is similar to that existing when the particles themselves are large; in such case the pore spaces are larger and the water films thicker. Such conditions increase the size of the pore space of the soil and make for easier penetration of both air and water. It is for this reason that farmers are eager to secure good aggregation or crumb structure in clay soils.

CHARACTER AND HABITS OF PLANT ROOTS AS THEY INFLUENCE IRRIGATION PRACTICE

Irrigation aids crop production by increasing root activity

31. The chief purpose of irrigation is to dissolve plant food and to supply water to the plant roots. Another purpose is to leach excess salts from the soil where they exist or to dilute the soil solution. A summary of these water, soil, root, and plant relationships, as they affect irrigation practice, is presented here in the form of quotations from the findings of those who have made field studies of the subject.

Roots do not develop in dry soil

32. Except as mentioned (Sec. 42), where root feeding occurs but root development is definitely limited, roots do not grow into dry soil. This fact is most easily observed in furrow irrigation, when the subbing water does not "reach across." Under the furrow there will be many roots, but in the dry zone between furrows there will be none. Also, no roots will be found below the soil depth to which the water has penetrated. (These statements do not take into account certain peculiar root habits of desert vegetation; they refer more especially to annual crops.)

It is obvious, then, that when water does not penetrate deeply or reach across from furrow to furrow, full advantage has not been taken of either the soil volume available or the tillage effort expended.

Roots grow to water; water does not move to roots

33. Since soil moisture below the field's holding capacity is, for practical purposes, stationary (Sec. 51), it follows that in order to obtain a continuing water supply roots must grow to the water. As noted in the quotations following, roots do exactly this, and that is why in the Southwest the practice has arisen of using the soil for depths of 3 to 10 feet or more as storage reservoirs for water. Roots have the power of making use of this stored water.

Roots grow deep in western soils

34. Roots of cultivated plants, contrary to current opinion, are not superficial but are deeply seated. Weaver (1).

Work done by the University of Arizona at the Experiment Station at Mesa, where the soil is of a rather heavy type, and at Tucson, where the soil is of a sandy loam nature, shows the average depth of penetration of the mature cotton roots to be from 6 to 7 feet and the working depth from 4 to 4½ feet.

Excavations made in May, 1924, in a wheat field at the Mesa Station showed wheat roots reaching a maximum penetration of 7 feet and a working depth of 3 to 4 feet. Clark (2).

In the quotations above, as well as in those following, the reader should understand that the working depth of roots does not mean the full depth to which roots feed, but only that level "to which the *bulk* of the roots penetrate, and in consequence, where they are very abundant." When the soil is moist below, a lesser number of roots penetrate to the full maximum depth. The factors determining this maximum depth are chiefly the plant's root habits, the depth to which the soil is moist, and the amount of soil air present at these depths. From the lower zones roots absorb both food and water, but it is the working depth which dries out most rapidly and completely and the one which therefore requires frequent refilling.

Extended examinations of the root distribution of winter wheat and rye at ten different stations in true-prairie and mixed-prairie areas of Nebraska, Kansas, and South Dakota show conclusively their deep rooting habits. The average maximum depth obtained by these cereals was 5 to 5.1 feet, respectively, while the average working depth (the soil level to which the bulk of the roots penetrate and consequently where they are very abundant) was 3.7 feet for wheat and 3.9 feet for rye. Other crops such as red clover and alfalfa were found to be rooted very much deeper. Weaver (1).

Roots draw both food and water from subsoils

35. The too prevalent idea that it is mainly the surface layer of soil that supplies the plant with nutrients, and that the subsoil is the plant's reservoir for water should give way to the fact that it is the whole soil mass permeated by roots that determines root activity. . . . It is well known and generally accepted that subsoils of arid regions are not unproductive and that in them, plants make a good growth. Weaver (1).

Large root systems promote high yields and water efficiency

36. The best developed root system (potatoes) was correlated with the greatest yield. . . . Here again, the yield (corn) 115 bu. per acre, was correlated with the best developed root system. Weaver (1).

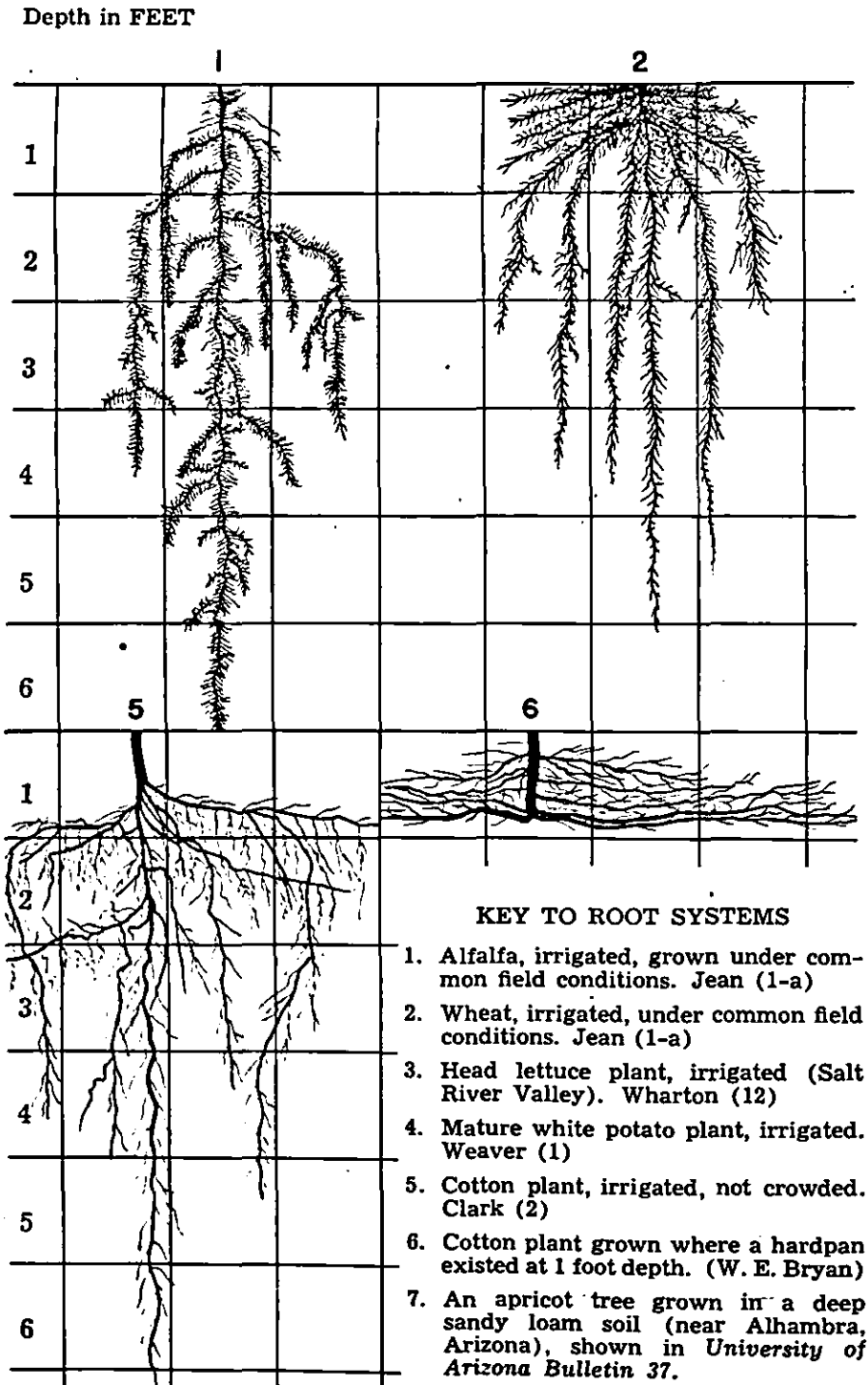
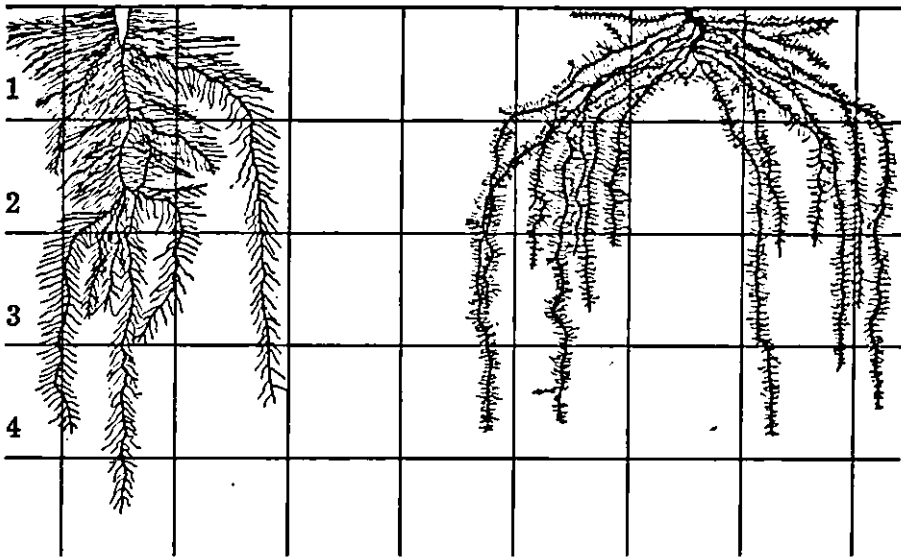


Plate I.

Depth in FEET
3



NOTE. — Drawing on page 18 shows Active Root Zone of very small plant—indicated by dotted area.

Depth in FEET

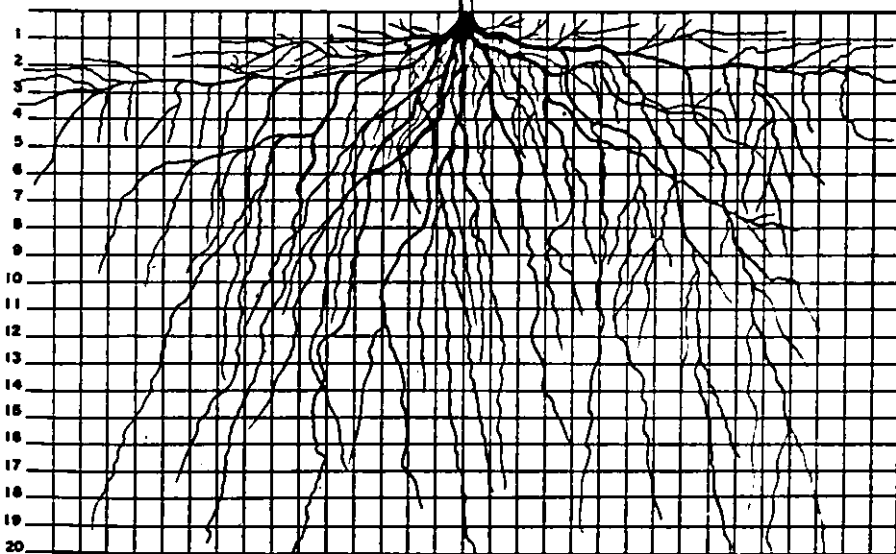


Plate II.

I would not advise the superficially rooted cotton plant . . . We have produced wonderful yields by that method, but it requires about 15 irrigations to accomplish it. King (3).

Roots adapt themselves to soil and moisture conditions

37. In the case of the 25 year old tree (citrus in the Salt River Valley) practically no roots were found below the 4th foot, due to the presence of a tenacious subsoil, but the 30 year old tree (citrus, Yuma Mesa) on deep sandy soil showed root development to a depth of 9 feet. Where the soil had been well fertilized and cultivated (3 to 6 year old trees, Yuma Mesa Citrus Experiment Station) more than 50% of the roots were located in the first 18 inches of soil. Crider (4).

A further known root habit is the fact that roots grow mostly at or near their tips. This subject is discussed in Section 132.

Roots make efficient use of soil stored water

38. Many cases are on record in Arizona in which crops have matured without rain or irrigation during much or all of their growth period.

A letter on file—written by the late H. D. Kochmeier of Casa Grande and dated July 4, 1923, some years before the San Carlos dam was built—relates that with but one very light irrigation on part of the 46-acre alfalfa field after March 14, the crop yielded 113 tons of hay in three cuttings. Only a large reserve supply of soil-stored moisture and a well-developed alfalfa root system to take advantage of this could have produced such results—almost 2½ tons per acre.

Miller (5) reports cases in Kansas where soil-stored moisture from irrigation water applied before the fall seeding grew and matured crops without further addition of rain or irrigation.

Before the building of the Aswan dam in Egypt, all cotton was grown on soil-stored water as the major water supply. Here again, such crop results could only have been the combined effect of large amounts of soil-stored moisture and well-developed plant root systems.

Roots at maximum as well as working depths promote production

39. Roots are said to have both maximum and working depths (Sec. 34). A glance at the root pictures on pages 14 and 15, and more especially at Figures 1, 2, and 5, will illustrate this point. From these facts, however, the reader must not attach merely minor importance to the lower or maximum depth roots. Because of the relatively few roots, the soil here is seldom if ever reduced to the wilting point in a single growing season. Therefore, this zone holds a continuing reserve water supply, even when the soil within the working-depth zone has become root dry. Because of this reserve the plant is carried safely through drought periods, even though the growth may be retarded.

Harris (6) says in unpublished correspondence:

In practice, these lower root zones, once filled in the winter or early spring, may be forgotten for the balance of the season, so long as the "working depth" zones are kept refilled.

Root absorption decreases as depth from surface increases

40. In *Technical Bulletin 181*, page 425, Irrigation Requirements of Cotton on Clay Loam Soils in the Salt River Valley (17), an illustration of the actual use by plants of water from different soil depths is given.

TABLE 2.—INCHES OF WATER DRAWN FROM EACH FOOT DEPTH BY PIMA COTTON PLANTS DURING GROWING SEASON

Depth in feet.....	1	2	3	4	5	6	Total
Inches of water used.....	8.7	7.3	5.7	5.3	2.0	1.7	30.7

From the figures shown here, it is apparent that the heaviest water use is from the first foot (evaporation loss must be taken into account); that the second heaviest is from the second foot, and that the amount decreases as the depth increases. However, as previously explained, the reserve in the fifth and sixth foot plays an important part in protection against temporary water stress between irrigations.

Roots remove moisture from some soil zones more quickly than from others

41. Since within a few days after an irrigation soil moisture is stationary (Sec. 51), except where "perched" water tables exist and since roots can draw moisture only from soil in contact with them, it follows that the soil will be dried out most quickly in those sections where the roots are most numerous and most active. This fact is important to the irrigator, more especially under certain conditions.

During the early life of the plant, when, for instance, it is but a few inches high and its root system but a few more inches in extent, the soil which is closest to these roots will be dried out faster than that some distance away or deeper in the soil. (See Figure 5 where *a* is the zone of most root activity and therefore of the greatest reduction in moisture. At *b* there are no roots and therefore there is no reduction in moisture.)

The lesson here is that an irrigation when the plants are small may result in marked growth response, even when most of the soil is fully moist.

Other illustrations of the habit of roots to dry out some soil sections more quickly than others are noted in the following citations:

Roots incline to abundant development, but retarded penetration when in contact with fertilized layers. Weaver (1).

Breazeale (7), in *University of Arizona Technical Bulletin 16*, notes similar effects when a small amount of organic matter is added to the root zone of a citrus seedling. The roots are matted about the organic material.

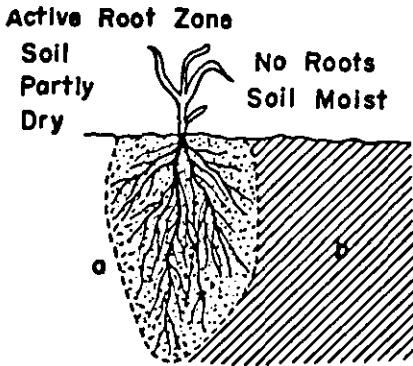


Figure 5.—Root absorption of young plants (a).

there is still moisture at the maximum root depths is permissible only during the later period of the plant's growth—at the "finishing maturity" stage (annuals). Dry zones during the growing season restrict growth.

Roots can transport moisture from point to point within the soil

42. An added reason why the storing of water in the soil to the maximum depth of roots may be noted in the following quotation:

A plant may absorb moisture from any soil horizon where water is available, for example, a subsoil, and transport this moisture to another horizon where moisture is scarce, for example, the surface soil. It may there exude this water, dissolve and absorb certain amounts of nutrient materials. Breazeale (7).

All evidence indicates that in spite of the fact that roots may be scarce at their greatest feeding depths they are, nevertheless, highly important. Their purpose is to insure the life and relative normalcy of the plant during periods of water stress. It may be noted here that Breazeale states also that the build-up of moisture by this means raises the soil moisture content only to the wilting point. At this moisture content roots can feed.

APPLICATION OF SOIL FACTS TO IRRIGATION PRACTICE

Penetration the irrigator's main problem

43. Since knowledge of the character of soils influences irrigation practice and the movement of water below the surface, just how can this knowledge be used in the field? Most of the discussion of such a subject may be included under the single heading *penetration*—the movement of water through soils.

For the purpose of illustrating and simplifying this rather complex subject, the authors have selected three particular soils,²

²See following page.

These extra-fertile layers or spots may be the result of any one of a number of causes, but in any case it follows that the soil within the fertilized layer will dry out more quickly than the rest of the root zone and that an irrigation will stimulate activity within this root cluster.

In general, the roots within the working depth are more abundant than they are lower in the soil, and the working depth zone will therefore dry out the faster.

Leaving this zone dry because

one from each of the three major soil classes: (1) sandy loam, (2) loam, and (3) clay. These specimen soils are briefly described below.

Sandy soils have easy penetration but low holding capacity

44. *Sandy loam* carries some silt and clay but is made up chiefly of sand particles. In order to use exact figures, the authors have selected a particular specimen from the sandy loam class. It holds about $\frac{3}{4}$ acre-inch of plant-available or refill water in each foot of depth.³ This soil may be described as one having an easy or rapid penetration and a relatively small holding capacity.

Loams take water more slowly than sandy loams but hold more

45. *Loam* is one of the medium-textured soils. It, too, carries sand, silt, and clay particles, but the percentage of silt and clay is noticeably greater than in sandy loam. The loams also vary in their ability to take and hold water, as their silt and clay content varies, and in these respects they lie between the sandy loams and the clays. The specimen here selected for illustration holds $1\frac{1}{2}$ acre-inches of plant-available or refill water for each foot in soil depth.

Loams may be generally described as taking water less readily than do the sandy loams, though still fairly easily, while their holding capacity is well above that of the sandy loams— $1\frac{1}{2}$ acre-inches as against $\frac{3}{4}$ acre-inch for each foot of depth.

Clays have slowest penetration but largest holding capacity

46. *Clay*. Any agricultural clay carries some sand and silt particles, but its particles are chiefly either silt or clay and the proportion of the latter is greater than in the loams. The clays, like the loams and sandy loams, vary in their water-taking and water-holding qualities. They take water more slowly but hold more of it than either of the others.

This particular clay specimen holds $2\frac{1}{2}$ acre-inches of plant-available or refill water per foot depth. It is not one of the heaviest clays. Its refill capacity is greater than that of the loams— $2\frac{1}{4}$ acre-inches against $1\frac{1}{2}$ for each foot.

³In laboratory terms, the three soils described here have moisture equivalent (M.E.) values of 10, 20, and 30 per cent, respectively. That is to say, each 100 pounds of fully dry soil of these classes has a total water-holding capacity of approximately 10, 20, and 30 pounds. These amounts when converted to acre-inches mean $1\frac{1}{2}$, 3, and $4\frac{1}{2}$ acre-inches for each foot of soil depth. However, since only about one half of the total water in a soil can be removed by roots, the refill necessary is approximately half of these amounts, or $\frac{3}{4}$, $1\frac{1}{2}$, and $2\frac{1}{4}$ acre-inches, respectively, for each foot in depth.

⁴This amount of water is approximately one half the total of water in the soil—the field water-holding capacity—but is all that the plant can withdraw and therefore all that is needed for refill irrigation.

TABLE 3.—SUMMARY OF SOILS USED FOR ILLUSTRATION PURPOSES

Number and soil class	Refill or plant-available water per foot depth (acre-inches)	Total holding capacity per foot depth (acre-inches)	Moisture equivalent (per cent)	Chief soil components
1. Sandy loam	$\frac{3}{4}$	$1\frac{1}{2}$	10	Sand particles
2. Loam	$1\frac{1}{2}$	3	20	Mixture of all particles
3. Clay	$2\frac{1}{4}$	$4\frac{1}{2}$	30	Silt and clay particles

PENETRATION RESULTS ON THREE SOILS

Soil class important in determining penetration

47. The fact is apparent that equal amounts of water give widely different penetration results on the different soil classes. The difference is also considerable for the soils within these classes.

A field having different soil classes will show varying penetration results

48. The irrigator cannot calculate the depth to which the water has penetrated unless he considers the class of soil with which he is working. The sure method, of course, is to dig or bore into the soil to see how far down it is wet, but the above figures give an idea of what to expect. They also indicate what penetration results may be secured when fields having different soil classes are given the same amounts of water.

REFILL REQUIREMENTS OF THREE SOILS

Figure 6 illustrates results obtained by applying 4 inches of water to each of the three soils described when these soils are root dry. Figure 7 illustrates the varying amounts of water required to wet these three soils to a depth of 4 feet.

Refill requirements depend upon soil class and previous moisture content

49. In Figure 7 are illustrated the amounts of water required to refill the three soil classes to a depth of 4 feet (Table 3). The soils are assumed to have been root dry before the irrigation. If they are not root dry, the refill requirements will be less by the amount of moisture remaining. Keep in mind that the soils used are special selections from their classes and that within these classes there is variation.

HOW WATER IS STORED IN SOILS

Soil moisture conditions at stated periods after flood irrigation where no plants are growing

Think of a field which has just been border irrigated with an average supply of water. The field has no crop growing or planted,

4 Inches of Water Soil Surface		Inches of Water		
		Sandy Loam	Loam	Clay
Will "refill" these 3 soils to depths shaded	1			
	2			
	3			
	4			
	5			
Depths reached by a 4 Inch irrigation, when soils are root dry.		5.3 ft.	2.65 ft.	1.77 ft.
"Refill" water required per foot of depth.		$\frac{3}{4}$ Acre inches	$1\frac{1}{2}$ Acre inches	$2\frac{1}{4}$ Acre inches

Figure 6.—Moisture depths in feet from a 4-inch irrigation.

and for the purpose of seeing what really becomes of this water—apart from root absorption—no crop is planted, nor is the field again irrigated for at least a year. The weeds, which are a type of crop, are regularly removed. The soil is examined as far down as it is wet, at intervals of perhaps one hour after irrigation; three days after, if it is a light soil, or ten to twelve days after if it is a heavy soil; and one year after for any soil. What moisture conditions should be expected at these various times? Roughly illustrated, they are presented in Figure 8.

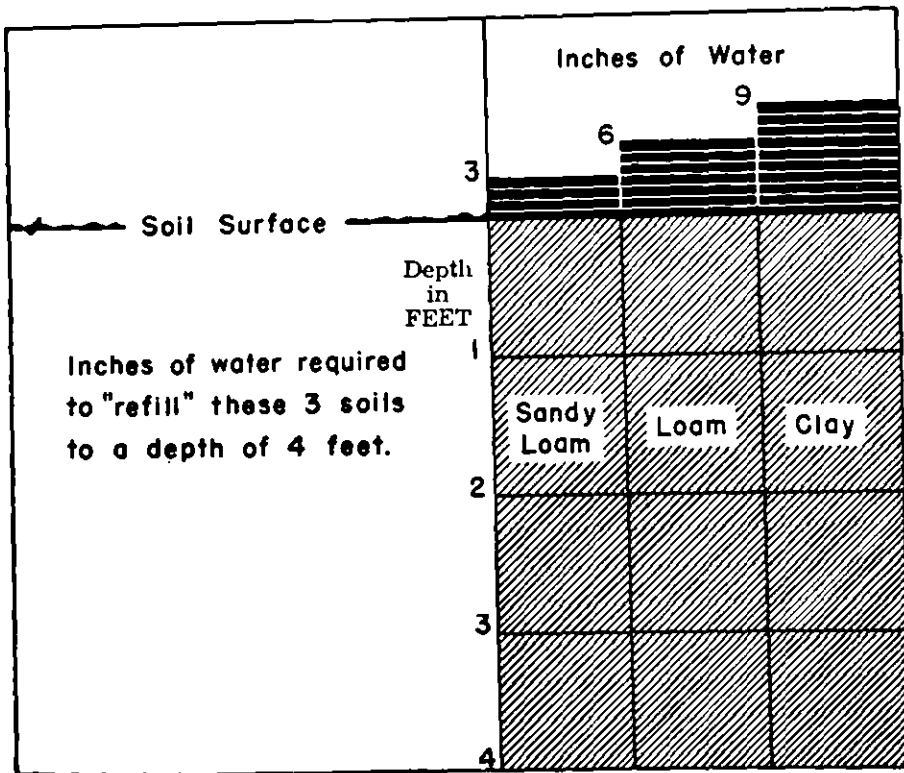


Figure 7.—The amounts of water required to refill these three soils to a depth of 4 feet.

Moisture movement downward continues while water above field-holding capacity is present

50. During and immediately following an irrigation, the top 6 to 10 inches of soil are saturated—all air spaces filled with water—and the process begins of moving this water to lower and drier soil levels. The water continues to move downward as long as any of the soil has water in excess of its holding capacity. To the limit of this holding capacity, the soil is the cheapest and most efficient water reservoir available for water storage.

Soil water becomes stationary soon after irrigation

51. The first few days after an irrigation dry the surface 2 or 3 inches; and the first few months, when not again irrigated, dry the top 6 to 8 inches to an air-dry condition. But below these surface stationary the moisture is stored and, for practical purposes, remains stationary over a period of many months. The only force having the power further to reduce this moisture in appreciable amounts is absorption of roots. These can reduce the stationary water about one half—to the wilting point. (See Fig. 8.)

The reader will probably recall an apparent exception to the condition just described. He will note that following an irrigation

the top soil dries out during the heat of the day but is remoistened at night. This moisture movement upward into the seed bed is, however, restricted to a comparatively short period following the irrigation. The time varies with the class of soil and the volume of water which actually penetrates. In any event, this upward movement ceases when the moisture content of the wet soil has fallen to, or somewhat below, the field-holding capacity. In actual practice, the time in which upward movement occurs varies from a few hours to eight or ten days. This transfer of soil moisture is the result of the forces of capillarity and vapor movement.

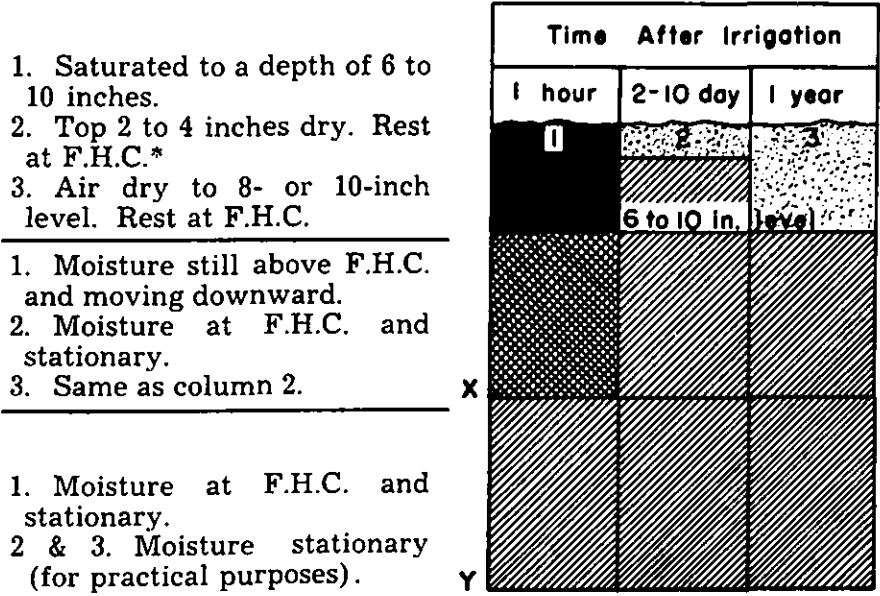


Figure 8.—How moisture is stored in soils.

Class of soil determines time required for soil moisture to become stationary after irrigation

52. The time required for the soil water to become stationary and the depth to which the water penetrates will depend upon the class of soil and the amount of water applied. (Because these vary, the depths in Figure 8 are marked X and Y as unknown factors.)

MOVEMENT OF WATER FROM FURROWS

WHERE THE SOIL HAS A UNIFORM RATE OF ABSORPTION

Water penetration from furrows shows pear-shaped pattern

53. When water is applied to a flat surface it moves downward more or less uniformly. However, when the water is confined in

*F.H.C. indicates field-holding capacity.

furrows its movement shows a quite different course, as may be noted in Figure 9. Here it is assumed that the soil is uniform to root depth—that is, within that depth there exist no soil layers of a more compact nature—so-called tight layers.

Water moves more rapidly downward than laterally

54. When the soil is uniform to the irrigation depth, the water from a furrow moves downward farther and more rapidly than it moves sideways, or laterally. (Note in Figure 9 the distance a—b as compared to c—d.) If the wetted portion below the furrow is dug out, it will be found to have been wetted in the form of a pear or an inverted cone. The depth of moist soil may be anywhere from twice to several times the lateral spread.

Sometimes the wet portions between furrows do not meet. Note: d—d and b—b.

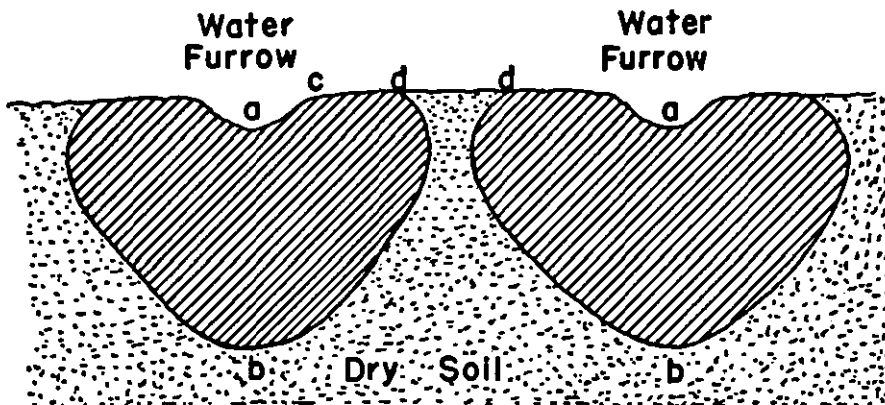


Figure 9.—Penetration pattern below the furrow in a uniform soil.

Land is unused when subbing water does not meet between furrows

55. When these wetted portions do not meet, much soil is left dry and therefore useless for plant feeding.

The corrections usually suggested for such dry soil conditions are wider water furrows, a longer irrigation period, or closer furrows where this is possible. For conditions where subbing or lateral movement is considerable, see Figure 10.

WHERE COMPACT OR TIGHT LAYERS ARE PRESENT BELOW THE SURFACE

For penetration results where the soil is not uniform but does contain layers that are more or less compact or tight for any one of a number of reasons, note the conditions shown in Figure 10.

Tight soil layers (A) frequently occur from plow depth down. These retard penetration and thus tend to build perched or temporary water tables (B). From these pools water subs by capillarity in any direction to drier soil sections (C).

Subbing water moves only from pools above or below surface

56. Within a short time after the water leaves the furrow, lateral movement ceases except as it may come from the perched water tables, as described. The amount of water in these temporary pools, either above or below the surface, will determine the extent of subbing; when the pools are gone, subbing ceases.

Perched water tables may help or hinder crop growth

57. The location of the tight layers, whether near the surface or well down in the soil, determines the benefit or harm arising from their effects on moisture movement. If they are too near the surface, the penetration depth will be shallow and the root zone restricted. But if they are down perhaps 3 feet or more, the subbing advantages may be considerable because of a constant water supply by capillarity.

Heavy irrigations and perched water tables may cause root suffocation

58. When perched water tables are present, care must be taken to avoid overirrigation. Otherwise the soil may be saturated to, or near, the surface, air excluded, and the plant roots suffocated. Roots of most crop plants will not grow into water-saturated soils. Barring this condition, the perched water table may act as a small storage reservoir.

Fluctuating water tables create problems

59. A difficult situation is one in which the water creating the high water table comes in from outside sources and is not the product of irrigation—at least on the field in question. The irrigator may reduce his own irrigations, but he can have little to say about outside, underground water movement. If the water level stands fairly constant at a reasonably efficient root-zone distance from the surface, the growing conditions may be favorable. If, however, the water table level fluctuates—rises and falls with the seasons—growth is impaired, especially for the perennials. Roots may develop in the moist soil when the level is low, only to be smothered when it rises. Brief periods of high water do not seriously affect the plant but prolonged periods do.

For consideration of such cases, the reader is referred to literature dealing with drainage. For alkali movement under such conditions see Section 72.

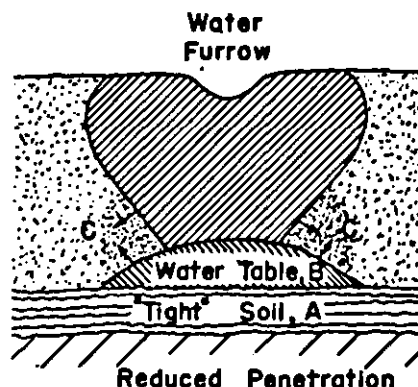


Figure 10.—Origin and influence of perched water tables.

THE CHEMISTRY OF IRRIGATION PRACTICE

By W. T. McGEORGE*

Irrigation water easily analyzed but results not easily applied

60. *Water.* In irrigated agriculture water is of course the greatest single growth-limiting factor, and profitable irrigated farming depends not only upon its low delivery cost and abundance but also upon its quality. Quality is usually determined by a chemical analysis. But after the chemical analysis has been made—a very simple procedure—it must be interpreted in terms of the *crop* and the *soil*—an extremely complex procedure. The chemical analysis is a set of unalterable facts; its interpretation is clouded by a mass of if's and but's.

Amount and kinds of salts (alkali) determine crop damage

61. *The crop.* All irrigation waters contain some dissolved salts. We know that an excess of soluble salt (call it alkali if you like) is injurious to crops. The extent of injury depends upon the amount and kinds of salt. These salts are largely bicarbonates, chlorides, and sulphates of soda, lime, and magnesia. They are not only harmless in small amounts, but most of them are actually plant foods and essential to growth. Therefore, in order to be injurious they must be present in excessive amounts.

Soil and water combined determine alkali damage

62. To interpret a water analysis one must know what represents an excess. Some salts are more injurious than others, and that complicates the picture. What makes it most difficult to arrive at an opinion is that, after all, it is not the kind or amount of salt in irrigation water which really does the damage; it is the amount and kind of salt present in the soil moisture; that is, the soil solution.

Water added to land dilutes soil solution; plant absorption increases its salt content

63. When irrigation or rain water is applied to land, the water immediately begins to lose its identity; that is, its chemical composition changes. The moisture content is always changing from a high point during an irrigation to a low point when the time arrives for another irrigation. Since the amount of salt in the soil remains the same, obviously the soil solution contains much more salt (a higher concentration) at the wilting point than it does when the soil is saturated with water.

Surface evaporation is heavy in hot climates, and salts are left on or near the surface

64. In a hot, dry climate, large quantities of water are returned to the air by direct evaporation from the surface of the soil; this

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of course leaves all its dissolved salts behind in the soil solution. Sometimes more are left behind than the soil solution can hold and thus a white crust of salt forms on the soil surface. If carbonate of soda is one of the salts, the crust will have a black color (black alkali). However, all black surface incrustations do not indicate black alkali.

Plants absorb water, reject salts, producing salt concentrations which may injure plants

65. Where a crop is growing on the land, a part of the soil water is drawn into the plant and evaporates into the air through the leaves. Since in using water plants reject all salts which they do not need—in so far as they are able to do so—they leave behind in the soil water which becomes more salt-saturated. If this rejected salt increases beyond a certain point in the soil solution the crop is killed.

Application of soil analysis to irrigation practice requires knowledge of crop, soil type, and cultural practices used

66. These are just a few of the if's and but's, but they are sufficient to show that in interpreting a water analysis the chemist must know something about the farmer's irrigation practice, his crop, and the type of soil he is farming; or the farmer must be in a position to apply the chemist's analysis to his system and thereby interpret it himself. Since the chemist rarely has all the needed information at hand when he makes a water analysis, he has established some arbitrary standards for irrigation water.

Suggestions on application of analysis figures to irrigation practice

67. A few of these standards are:

1. A good irrigation water is a hard water (high in lime salts).
2. It should contain no carbonate of soda (black alkali).
3. On the basis of total salt content,
 - 500 parts per million or less is a very good water.
 - 500 to 1,000 parts per million is a good water.
 - 1,000 to 1,500 parts per million is a fair water.
 - 2,000 or more parts per million is a poor water.

Results depend upon practices as well as upon salt content of water and soils

68. As has been stated, these salt content values are arbitrary figures intended for all possible conditions. However, many farmers are using irrigation waters containing more than 2,000 p.p.m. salts and are growing good crops, because they have learned by experience how to use such waters for the kinds of crops they are growing and for the soil types they are farming. For example, a sample of water was recently analyzed in the Experiment Station laboratory and found to contain over 4,000 p.p.m. salt, yet it had been in use for many years on alfalfa, producing excellent yields of hay.

Salty irrigation water injures soils as well as crops

69. *Soil.* Once the irrigation water reaches the soil, "anything can happen." Irrigation water carries salts in solution, and when salts are in solution they are in their most active form, chemically speaking. The mass of particles which make up the soil, broken-down or disintegrated mineral and rock particles, are wide open to chemical attack from the salts in the water and even from the water itself. It is clear then that a farmer must give much thought to the effects of salty irrigation water on the soil as well as on the crop. The following case will illustrate this.

Chemically soft water injures soil rather than plants

70. Some time ago a sample of water was submitted to the Experiment Station laboratory for analysis, accompanied by the statement that it had killed the plants which were irrigated with it. The analysis showed that it was an extremely soft water (high in soda). In fact, it contained no lime salts at all. Since soft water does not kill plants but does wreck the soil's physical condition, the source of this sample was investigated and it was found that the grower was irrigating a garden with water obtained from the Southern Pacific water-softening tower in Maricopa. The result was that the soil had become so tight that the plant roots could not grow in it, neither water nor air could penetrate it, and worst of all, the soft water had changed the soil into a black alkali soil. It was completely dispersed.

Soft water makes hard land and hard water makes soft land

71. This case is cited because it is the best object lesson which has come to our attention indicating that soft water makes hard land and hard water makes soft land. Or, stated in another way, soft water will lead to black alkali and hard water prevents the formation of black alkali. Make sure that water contains more lime salts than soda salts, or enough to prevent the soda from getting control of the situation, and 90 per cent of the soil troubles arising in irrigated agriculture will be avoided.

MOVEMENT OF SALTS BY IRRIGATION WATER (FURROW IRRIGATION)

Kinds and amount of salt determine injury

72. Young plants or seedlings set on the top of the ridge may be injured by passing through the salt zone. The situation is a problem only when salts of a specially soluble character are present in considerable quantities in the soil or when the water itself carries a heavy salt content.

DEFINITIONS OF CHEMICAL TERMS COMMONLY USED IN IRRIGATION PRACTICE

1. *Hard water:* Water containing enough lime salts to offset the soda salts and thus prevent soda or black alkali injury.
2. *Soft water:* Water not containing enough lime salts to react as in (1).
3. *Alkaline soil:* Any soil which is alkaline (not acid) in reaction or which has a pH value above 7.3. (See chart, Fig. 21, and 73,3.)

- Any soil with a pH below 6.6 is acid; one with a pH between 6.6 and 7.3 is in the neutral range.
4. *Alkali soil*: Any soil containing alkali salts, further divided into:
 - a. *White alkali*: One containing only neutral salts.
 - b. *Black alkali*: A soil containing carbonate of soda, in addition to the salines (neutral salts).
 5. *Calcareous soil*: A soil containing enough calcium carbonate (caliche) to be alkaline (above pH 7.3).
 6. *Flocculate*: To aggregate the soil particles into groups, granules, or crumbs (Sec. 12). Decaying organic matter has this effect.
 7. *Deflocculate*: To disperse or break down these granules or crumbs into their soil particles. Black alkali has this effect.

For a more complete discussion of this subject, see *University of Arizona Bulletin No. 123 and No. 182*.

Soil salts accumulate on or near ridge top

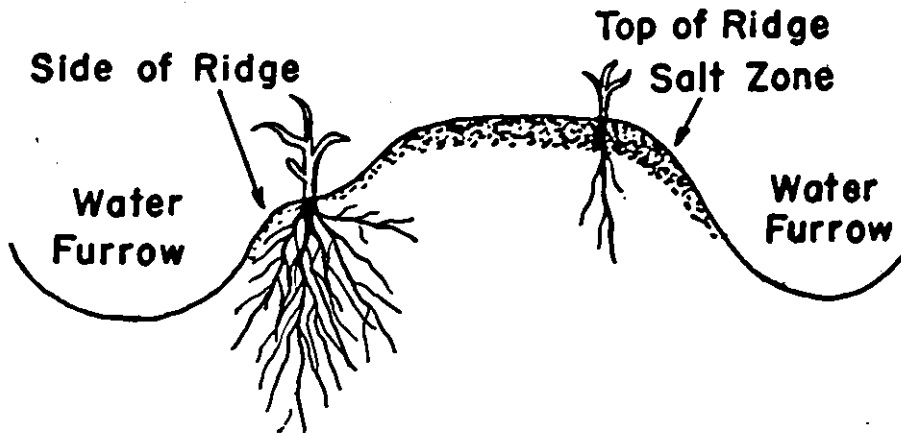


Figure 11.—Two types of double-row planting and alkali accumulations at the surface.

Subbed water rises to the top of the ridge and evaporates, leaving a salt deposit.

Plant roots on the ridge top (right) must start in and grow through this salty soil layer.

Plant roots on the side of the ridge (left) start and grow below the salt zone.

TILLAGE PRACTICES AND PUDDLED SOILS

BY R. L. MATLOCK*

Puddling, compaction, and dispersion retard penetration

73. In field practice there are three quite distinct arrangements of the soil particles and crumbs, all of which retard water penetration. While these resemble one another somewhat, both in

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appearance and final effect, they are nevertheless the result of quite different causes. The means for their correction must therefore be different in each case; this makes necessary a decision as to which of the three conditions exists. They may be briefly defined and described as follows:

1. *Soil puddling* is a process by which the soil crumbs and particles cement together into a more or less impervious mass. It occurs only when the soil is worked at a moisture content above that of good working condition but below saturation. The soil must be in the plastic or sticky stage of wetness. It requires mechanical pressure such as that exerted by tillage tools, and it takes place only in those soils carrying a considerable percentage of clay particles.

2. *Soil compaction* may occur in any soil, wet or dry. The crumbs may or may not be broken, but the original volume is compressed into a smaller one. The pore spaces are thus reduced and penetration retarded until the land is again worked. Roads across fields show this effect. When the soil carries clay particles and is wet to the point of stickiness, compaction can cause puddling.

3. *Dispersion (chemical)* occurs when black alkali is present in the soil. The crumbs break apart into their original particles—sand, silt, and clay—and these settle so closely together that both air and water are largely excluded. Special moisture content or mechanical pressures are not necessary; the action is strictly chemical.

An exception to the above is noted in the case of sands, where no further division of the particles is possible; penetration is therefore not affected even though the alkali be present.

Nothing more need be said on compaction except that it is a common cause of uneven penetration and therefore of uneven soil moisture distribution. Dispersion is defined by McGeorge in Section 72 (3) and needs no further mention. The discussion on puddling is continued herewith.

Puddling retards penetration and reduces root absorption

74. As has been explained, puddling so compacts the soil that the penetration of irrigation water is greatly retarded. Also the water actually retained in the puddled portion is held so tightly that plant roots are able to absorb but little of it. The lack of air penetration interferes with normal root development.

The harm resulting from puddling is therefore apparent, and the irrigator naturally wishes to know what tillage practices cause puddling and what other practices will prevent the condition or reclaim land already affected.

Not all soils puddle

75. First of all, it should be noted that with the same sort of faulty practices one soil will become puddled much more readily

than another. A sandy soil can scarcely be handled so as to puddle it, while some clay soils cannot be worked, even to the point where they are almost dry enough to bake, without becoming puddled.

Improper leveling may result in puddling

76. The problem with heavy soils often is shown when the land is improperly leveled. Low areas which are overwatered do not dry out enough to be in condition for disking with the rest of the field and, since it is not practical to skip those areas, they become puddled by the disking.

Organic matter aids in preventing puddling

77. We know, too, that a soil well supplied with organic matter will not puddle so readily as one in which the humus has been burned out.

Heavy machinery tends to promote puddling

78. It is generally believed that the use of heavy equipment is more likely to cause puddling than are horse-drawn tools or light tractors. This emphasizes the fact that while users of large-scale machinery can get over the ground more rapidly they also have a shorter safe-from-the-danger-of-puddling period in which to prepare a seedbed or to do cultivating work.

Livestock may or may not cause puddling

79. Grazing livestock on wet fields sometimes causes puddling; yet if the land is actually covered with water, puddling may not occur. This fact is explained in *University of Arizona Technical Bulletin No. 67* and *No. 100*. Briefly, they state that soils puddle only within a rather narrow range of moisture content—a few degrees of moisture content above and below the moisture equivalent. This measurement is closely related to the field-holding capacity, which in turn represents a soil moisture content somewhat above good working condition.

Summary of rules for avoidance of puddling

80. A summary of good practices for avoiding puddling:

1. On heavy soils, especially, maintain a good supply of organic matter.
2. Level the land so as to secure uniform wetting of the surface.
3. By trial and error methods determine the safe workable conditions for the soil in question: if it makes a good mud ball it is far too wet for work. If upon application of pressure after compaction the soil readily crumbles, it is in safe working form.
4. With easily puddled soils allow more complete drying before beginning any tillage operations with heavy equipment.
5. After irrigations or heavy rains keep stock off fields where the soil is heavy until they make only shallow hoof marks.

CURING A PUDDLED SOIL CONDITION

Puddling process not fully understood

81. Until we know more about the factors which cause puddling in the field or how to correct a puddled soil condition, it is difficult to give directions on methods of overcoming it. Under some conditions soils have been known to remain puddled for a longer time than one crop year.

Fall plowing helps correct puddled soils

82. As a rule, however, a soil which has been puddled during the summer season can be brought back into condition by the following spring. Such land should be fall plowed and left rough to go through the winter undisturbed. Seemingly, exposure to sun and air, to temperature changes (where the soil freezes, puddling generally is overcome as a natural process), and to such wetting and drying as may occur usually corrects the puddled condition. Under most Arizona conditions, the wetting and drying process, followed by tillage when the soil moisture is right, proves to be the most practical cure for a puddled soil.

Correcting puddled spots a nuisance

83. Where puddling has occurred in small areas as a result of faulty land leveling, it may be impracticable to try to cure the condition during the current growing season. Such areas would have to be diked off to allow them to dry out; this would require a longer time than for adjoining unpuddled areas to dry out after an irrigation. Cultivating equipment would have to be kept off the small puddled spots, and that would be a nuisance.

Complete drying, organic matter, and leveling remove the spots

84. Following removal of the crop, however, the whole field can be dried out thoroughly. This is the first step in curing the puddled condition.

After the puddled areas are dry, it is well to apply generous amounts (10 or 12 tons per acre) of organic matter—animal manure, plant trash, straw, or almost any refuse—to the areas where it is at all possible to do so.⁴ The field should then be plowed and leveled to correct the faulty spots.

Prevention of puddling easier than correction

85. If the field is allowed to dry out again after the above treatment, the puddled condition should be completely cured with ordinary tillage operations. From here on, the object should be to handle that particular soil in such way as to prevent any recurrence of the trouble. Puddled soils do not produce good crop yields and are expensive to till.

⁴Organic matter in the soil promotes the formation of granules or crumbs, and when the crumb structure is good, puddling seldom occurs.

PENETRATION PROBLEMS AND IRRIGATION PRACTICE

Soil penetration problems difficult

86. It is one thing for the irrigator to decide how much water he needs in his soil and where he needs it; it is quite another to determine how best to place it there. Of the numerous factors involved, the one usually the most difficult is penetration. Soil and water relations are many, and not all of these are as yet understood. A few of the more important of these relationships as they occur in the field and influence irrigation practice are discussed here.

TIME PERIOD IN IRRIGATION

Time the water is on the ground is a leading penetration factor

87. Probably the most important single factor in influencing the depth of penetration—or, in the case of a soil of uniform absorption, of subbing—is the time the irrigation water remains on the surface. In Figures 12 and 13 a quite common underground condition in irrigation areas is illustrated.

Long borders frequently show uneven growth

88. In these figures the fact is illustrated that the growth throughout long borders is frequently uneven. In Figure 12 the growth near the head end is good, but it gradually decreases until at the lower end the plant size is definitely inferior.

In Figure 13 growth at the upper and lower ends is good, while a space between shows a decreasing growth as the distance from the head end increases; shortest plant heights are found at about four fifths of the distance down the border.

Both the above conditions are frequently noted in irrigated fields where the borders are long.

The time factor explains four-fifths zone

89. The explanation usually offered for the condition shown in Figures 13 and 14 is that water running down the slope of the border is on the upper end for a longer time than on any other part. Thus, as the distance from the head end increases, the time the water is in contact with any portion of the border naturally decreases. The penetration depth therefore decreases as the distance from the head end increases. As was stated in the discussion of roots, the depth of penetration has much to do with the extent of the root system and, through this, with the above-ground plant parts. Such is the explanation when the plant size steadily reduces, as it does toward the lower end.

However, another factor frequently intervenes. Cross borders are sometimes used at the lower end to prevent runoff, and these pond up the water over a portion of the border. Seldom, however, does this effect reach back to the four-fifths section; so this latter

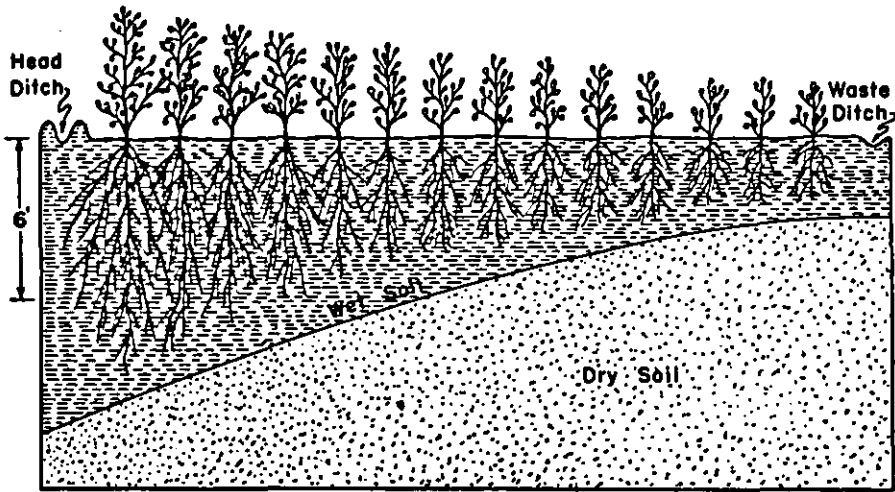


Figure 12.—A similar field condition when there is a free runoff.

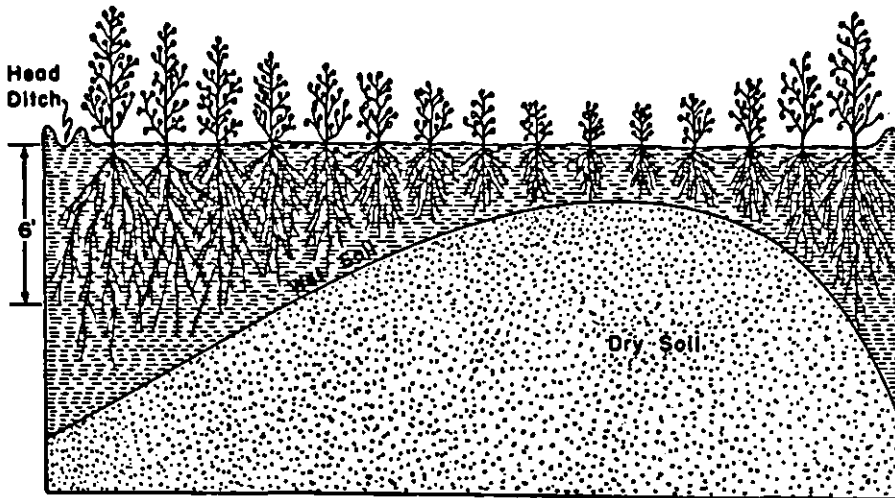


Figure 13.—Penetration is roughly proportional to the time the water is on the surface. Here is shown the relative root and top growth of the cotton plant on certain long borders when the water is dammed back at the lower end.

area gets the shortest watering time and the poorest penetration, with the result that it makes the poorest growth (Fig. 13).

Irrigation time, penetration depth, root extent, crop production are related

90. As the diagrams show, there is a rather close relationship among these factors: (1) length of time the water is on the ground, (2) depth of water penetration, (3) extent of the root systems, and (4) crop production. This relationship is usually evident in the average irrigated field. Type of soil, length of run,

and size of head must all be taken into account in determining the best methods to use, and the irrigator, realizing the nature of his problem, can best decide the remedy for each particular case.

Regulating the head can be used to produce more even penetration and growth

91. There are two general methods of attack. One is to use a large head, which would reduce the time the water is on the border and therefore the time-difference between the upper and the lower ends. This method causes an excessive run-off. The other is to use a small head, which would increase the total irrigation time and thus the time on the lower end. It would also increase the difference in time between the upper and the lower end flow periods. This method wastes water through excessive penetration at the upper end.

In either case, there is a considerable waste of water.

A combination of the two methods is suggested. Use a large head until the water reaches two-thirds or three-fourths of the way across the field, and then cut the head to suit the conditions. Obviously, the time the water is on each end will be more nearly equal than when a constant head is used. Harris (6).

OTHER CAUSES OF RETARDED PENETRATION

Dry areas frequently occur in middle root zones in late summer

92. Another soil condition showing a lack of penetration frequently has been reported. It is described in the following quotation:

A condition often encountered is one in which there is a middle zone in the root system, from about 2 to 3½ feet depth, which probably absorbs but little moisture after August 1 to 15, since the surface application fails to penetrate to that depth as it did during the earlier part of the season. King (3).

Apparently, these middle root zones, once dried, are difficult to rewet. But regardless of the cause of this—and the reason or reasons do not appear to be agreed upon—the corrective plan might well be an extra effort to secure penetration. On this point King (3) remarks, “[Use] better levelling of land, and longer applications of water.”

A system of frequent light irrigations is sometimes used in such cases but, as is suggested in Section 36, these are wasteful of time and water and are not advised where they can be avoided.

Water penetration sometimes retarded as the season advances

93. Another case of lack of penetration, especially during the summer season, is illustrated in the common irrigation experience where during the spring and early summer it requires a much longer time for the water to get through than it does during July and August. Since, then, the depth of penetration is roughly proportional to the time the water is on the ground, the net penetration for these later months is much less than it was during the early part of the season.

This shortening of the time required to get through is doubtless partly the result of the causes mentioned by King and Harris,

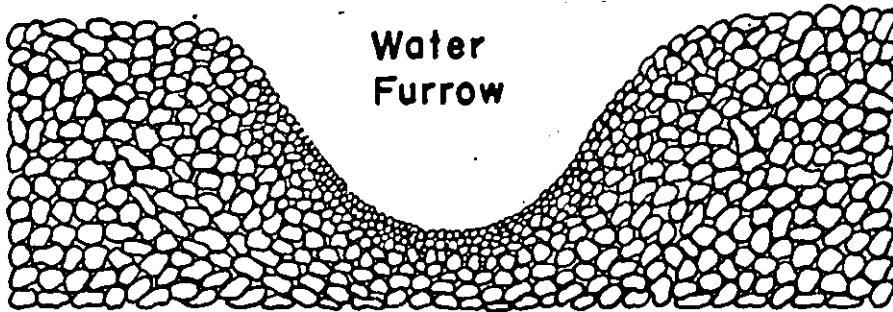


Figure 14.—The silting-up process.

and it may also be due in part to a puddling effect at the bottom of the furrow resulting from the impact of tillage tools. A further suggested cause is that the retarded penetration is due to a silting-up process below the furrow, as is explained in the following section.

Silting-up below furrow impairs aeration and penetration

94. Figure 14 illustrates the silting-up process. Here it is seen that the soil immediately below the furrow is of a more compact make-up than is that in or below the ridge. The pore spaces between the larger soil particles have become somewhat clogged with the finer particles washed down. The effect is frequently noticeable to a depth of 2 to 4 inches. Penetration is naturally retarded.

This irrigation result is usually considered as the reason for planting many crops, especially root crops, on ridges. The soil in the ridges and below them carries less of the finer particles and is therefore less compact and better aerated. It has also been suggested that the silting-up process is responsible for the so-called border effect which is frequently noticed, not only in row crops but also in border-planted grains.

The condition described here as border effect shows up in many irrigated fields as a restricted growth within the borders and a noticeably heavier growth on the border ridges. The causes of this are not fully agreed upon.

The natural correction for such a condition is to reduce the grade and head, thus slowing down the stream and reducing the washing effect. A longer time period is indicated, since fast water washes.

Some soils take water faster in cool weather than in warm

95. Penetration difficulties are also reported as having occurred more often in hot than in cool weather on some heavy soils. For extreme cases the only remedy, aside from those already mentioned, which has been used effectively is a swing-over from hot- to cool-weather crops—from cotton and alfalfa to the small grains or winter-growing legumes.

Chemical composition of some soils retards penetration

96. As was explained in Section 70, certain alkali soils "freeze up" and will not take water. In such cases the cause is chemical and the treatment must also be chemical in its effects. These soil conditions vary so widely and require such different methods of handling that they are but briefly mentioned here, and the reader is referred to McGeorge's section, "The Chemistry of Irrigation Practice" and to publications dealing in detail with this subject. (See list of publications, page 58.)

Decaying organic matter influences chemical nature of soils

97. Where practicable, the use of organic matter is highly recommended as a corrective for alkaline or alkali soils. Its effect during decay or decomposition is to produce carbonic acid, which substance tends to neutralize the excess of alkaline salts present and thus to bring about a better granulation of soil particles. For a discussion of this subject the reader is referred to *University of Arizona Technical Bulletin 41*.

Gypsum and sulphur recommended correctives for alkali soils

98. Other means recommended to correct strongly alkaline or alkali soils are the application of gypsum or of sulphur. The use of gypsum for this purpose is discussed in *University of Arizona Bulletin No. 123* and *No. 182*. The use of sulphur for such a purpose is a newer practice, and the reader is referred to *University of Arizona Bulletin 182*.

The effect of either of these materials is an increased granulation of soil particles and therefore a more rapid water penetration.

However, as explained by McGeorge, the interpretation of soil facts is extremely complex, and readers are advised to try out these materials on their own lands in a small way before adopting the practice generally. The use of sulphur and gypsum has not as yet been fully demonstrated on all types and conditions of soil.

High spots reduce crop yields

99. Another common cause of poor and uneven penetration is high spots in the field. The effect of these is frequently overlooked because the water usually covers them for a time, and their height above the general ground level is often barely noticeable without the use of a level. Harris (6) reports that elevations of $\frac{1}{2}$ inch have caused serious lack of penetration and crop growth. Here again the time factor—the time the water is actually on the surface—is the operating cause. The correction for this is better leveling.

Growing crops check speed of water

100. In the discussions above, especially those relating to the speed of water, a bare soil was assumed. However, when there is a growing crop, such as alfalfa, the small grains, or pasture,

the effect is to retard the flow in proportion to the density of growth. With this slower rate all the advantages mentioned as resulting from reduced speed are gained, and the total effect depends upon the kind of crop and the thickness of the stand. Since such conditions relate to special irrigation practices for particular crops, they are not further discussed here.

INFLUENCE OF LAND SLOPE ON PENETRATION

Land slope is a leading penetration factor

101. An important factor in securing penetration is the slope of the land, both in the direction of, and laterally from, the water flow. Many conditions are involved, and a few of the more obvious are discussed.

In considering slope, it is well to keep in mind the following soil-water relationships.

1. The velocity of the flow of irrigation water is dependent on the slope or grade, and the volume of the flow, or head, is relative to the width of border or number of furrows.
2. The penetration secured from an irrigation is proportional, though not directly so, to the length of time the water is on the surface.
3. Fast-moving water is less effective than is more slowly moving water in securing deep penetration.
4. Fast-moving water washes and is inclined to silt up the soil, more especially below water furrows, thus retarding penetration.
5. Fast-moving water reduces the time the water is on the surface and thus reduces the net penetration. Or, if the flow is continued, the runoff is increased.
6. The heavier soils (loams, silts, and clays) require more time for a given penetration than do the lighter soils, the sands and sandy loams.

Soil class, slope, and head determine border, furrow arrangement

102. With the above facts in mind, the irrigator will realize that irrigation plans must include consideration of many factors. Thus, a small head of water on a wide border and over a sandy loam soil might fail to get through and result in an unnecessarily deep penetration at the upper end of the border. The same head of water over a border of equal size but on a clay soil might give a satisfactory and uniform penetration.

Large heads and short borders indicated for sandy soils

103. Generally speaking, best results are obtained in irrigating light or sandy soils by using comparatively large heads of water on relatively short borders with a reasonable amount of slope.

Such conditions permit a quick run and therefore a minimum waste through excess penetration at the head end. Excess penetration not only wastes water but also leaches the soil. The irrigator must choose between the inconvenience of short borders and the money loss from wasted water and fertility.

Slow water and long borders desirable on heavy soils

104. On the heavier soils, where excess penetration is not likely to occur, there is advantage in reducing the slope and lengthening the border, provided the condition shown in Figures 12 and 13 is avoided. On normal clay soils the slope may be reduced, where feasible, to a grade of .5 or 1 inch per 100 feet and the border length to $\frac{1}{4}$ mile. These figures are approximate and merely for illustration; actual conditions will have to govern, since all descriptive terms are, of necessity, relative.

Size of head important in irrigation plans

105. In all these calculations the size of the head, whether expressed as gallons per minute, cubic feet per second, or miner's inches, must be considered and the border or row arrangements adjusted accordingly. A small head will require small dimensions, a large head larger dimensions—rows or borders. Where the head is necessarily small the border width should be relatively narrow so that full coverage of the ground may be insured and the rate of flow sufficient to get through in reasonable time.

Side slopes need consideration

106. Where the land slopes, not only in the direction the borders run but also at right angles to them, new problems arise. Where it is possible to eliminate this slope by cross-leveling or contour bordering, it should be done. Where such a plan is not possible because of shallow soil conditions, special methods should be used. Side slopes produce both soil washing and uneven penetration.

Uneven penetration a common effect of side slopes

107. Should the water be, let us say, 4 inches deep on the lower and but 2 inches on the upper side of the border, the net result would be an uneven penetration and therefore an uneven crop growth. The fact is readily seen in the crop or found by a soil examination. Water remaining on the surface of the lower side for a longer time than on the upper side effects this result. It is another time-period effect.

Contour bordering, leveling, and use of furrows help correct side slope effects

108. As far as possible, releveling should be done and the borders laid out so as to reduce the side slope to a minimum. When this is not sufficient, furrow irrigation may be used for row crops and corrugated irrigation for the others. A corrugator is any kind of

tool which makes shallow furrows fairly close together (8 to 16 inches) which will direct the water forward, thus aiding in overcoming the side-slope influences. This method demands the careful adjustment of the head so that the small furrows may be full but not flooded.

In using all kinds of furrows, corrugations, or borders on a side slope, care should be taken to avoid the use of too large a head or to permit an accumulation of trash which will back up the water. Otherwise a break through of the border or furrow ridge starts a side wash not easily stopped. If a border is used, in addition to furrows and corrugations, side washes due to breaks are more easily controlled. They may be restricted to the border in which they occur.

BORDER PROFILE ARRANGEMENTS

To avoid a common lack of penetration on the lower portion of long borders or, as it is frequently expressed, to eliminate the four-fifths zone, constitutes a major problem in irrigation. The following is a brief discussion of some of the types of border profile used to minimize this unfavorable condition.

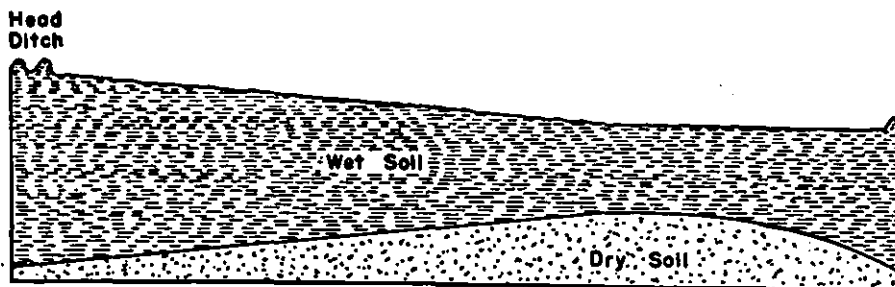


Figure 15.—Nonuniform slope.

Nonuniform slope

109a. Figure 15 shows a suggested border profile designed to increase penetration depth in the four-fifths zone by decreasing the slope in that zone relative to that at the upper end of the border.

In this case, the slope used is not uniform but is relatively steep on the first half of the border and flattened somewhat on the lower half.

It is evident that the water on the upper end of the border where the slope is steep will flow faster than it will on the lower end where the grade is reduced or flattened out. The effect of this arrangement is therefore to reduce the time the water is on the upper end and to increase the time it is on the lower end, thus tending to make more nearly uniform the time period and therefore the penetration throughout the border.

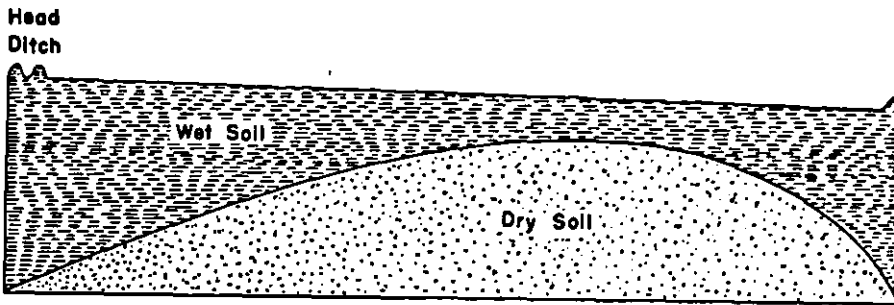


Figure 16.—Uniform slope.

Uniform slope

109b. In Figure 16, the profile shows a uniform slope throughout. This is the most common type of border used, but it is also the one in which is found the most pronounced four-fifths zone effect.

In the case of open-textured soils, the result is deep percolation losses at the upper end, and a similar loss on a narrow strip at the lower end when the water is held up there. In such a case, there may be no four-fifths zone effect, and the injury consists in water loss only.

When the soil in question is more or less impervious, the normal result is insufficient penetration in the four-fifths zone, or in all the lower half if cross borders at the end are not used.

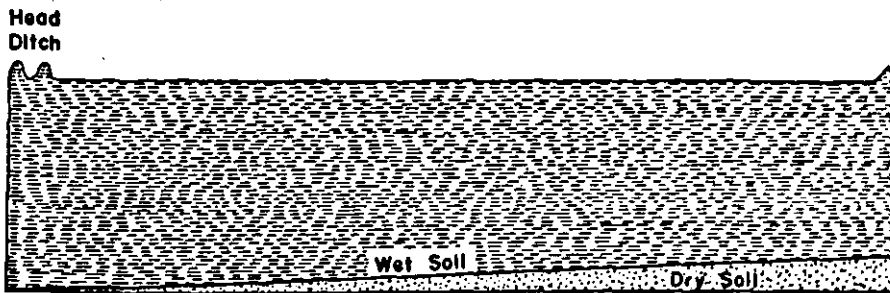


Figure 17.—No slope.

No slope

110. Level plots, with or without border checks, are adapted to conditions where the land is comparatively level, where the soil is more or less tight, and where relatively large heads of water are available. The system is adapted to borders of maximum length of probably not over 400 or 500 feet. Under such conditions this type of border profile is capable of producing any desired even penetration throughout the border length. It is simply a matter of applying enough water.

The fact bears repeating that bordering systems and border profiles must be arranged with due consideration to soil class and type as well as to natural slope.

In concluding the remarks on penetration, it may be stated that under severe conditions, where good penetration is difficult to secure by any border arrangement, the plan of using small heads of water for long periods of time is the best-known remedy.

To accomplish this, operators have frequently resorted to the use of spiles and tubes that restrict the flow. The spiles are those in common use among truck producers and are made of ordinary lath nailed edge to edge to form a box with about 1½-inch orifice. The tubes are made of rubber hose, plastic, or old iron tubing. Any of these is placed either under or over the ditch border, and when it is necessary to start the flow, suction is applied. This flow may be continued as long as water is available.

Of course, such unfavorable penetration conditions call for a long-time program of soil improvement—a better aggregation of soil particles and consequently an easier water penetration. Plans to accomplish these results are discussed in Section 12.

IRRIGATION OF CROPS—QUANTITY

Water needed depends upon many factors

111. The question of how much water is needed to produce a crop cannot be answered with any great degree of accuracy unless all the growth conditions are known; that is, unless we know at least the climate, the soil, and the nature of the crop to be grown. These growth factors affect, not alone the amount of water actually used by the plant, but the extra amount which must be applied to take care of the surface evaporation, ditch loss, runoff, and other losses—avoidable or otherwise.

However, it is of practical value to have some basic figure in mind. Let us assume an average ranch located in the Salt River Valley, one having a reasonably fertile soil with an even rate of absorption. Here the crop irrigation requirements would approximate the figures shown in Table 4. These data are taken from the report, "Crop Acreages and Water Required," by Charles Hobart, Assistant County Agent, Maricopa County.

TABLE 4

Crop	Weather conditions during major growth period	When approximate yield per acre is	Amount of water required (acre-feet)
Alfalfa	Both cool and warm	5 tons.....	5
Cotton	Warm	1,000 lbs. of seed cotton	3
Wheat (grain)	Cool	1,500 lbs.....	2
Cool-weather vegetables	Cool	Average	2½
Orchard	Both cool and warm	Average	3-5

With the above table as an assumed standard of measurement, we shall consider some of the variations from this, made necessary by changes in conditions from those stated.

Growing plants use more water in warm weather

112. Plants, like people, drink more water in warm than in cool weather and for the same reason—greater transpiration (perspiration). Therefore, plants producing most of their growth during the hot weather of summer actually use more water than those growing in the cooler weather of winter, spring, or fall. This is true for all sections where growth occurs during the different seasons. It must also follow that more water is used by plants growing in the lower-altitude warm areas than in the higher-altitude cool areas. To the above must be added the fact that winds, especially warm winds, increase the plant's transpiration and therefore its water use. Surface evaporation also is heavier in warm weather than in cool. (For a discussion of the subject, "Water Requirements of Plants," the reader is referred to Briggs and Shantz, *Bureau of Plant Industry Bulletin 285*.)

Rainfall reduces irrigation requirements

113. In those areas of the state where the average annual precipitation (rain or snow) is considerable—above 12 or 15 inches—this becomes a factor in the water supply; and the amount of irrigation water applied may be adjusted downward as the total precipitation moves upward. Since the farmer cannot regulate either the time or the amount of precipitation, irrigation practices in such areas present problems that can be solved only as and where they arise.

More water required for infertile soil than for same soil fertile for same weight of crop

114. For a more detailed discussion of this subject, see Section 136.

Efficient use of water reduces amount required

115. The amount of water wasted, avoidably or otherwise, is another factor determining quantity. Illustrations are: runoff, surface evaporation, poor stand of plants, poor soil structure, excess of salts, and poor leveling. These losses are discussed elsewhere in this publication.

Poor timing of irrigations wastes water through impaired production

116. Plants can be stunted or their growth checked by a too-long-delayed irrigation. Also, the irrigation of some crops at certain times may stimulate foliage when fruitage is desired. In the case of most vegetables where a quick, succulent growth is needed, a delayed irrigation will check growth and impair quality. In all such cases the amount of water beneficially used is too large for the crop results produced—the water has not been used effectively.

This subject relates to the irrigation of particular crops and will not be further discussed here.

Crops vary in water requirements

117. Different crops are said to have different water requirements; that is, they differ in the amount of water actually needed for the plants' use. Whether this difference is due to the actual needs of the plants or to the season of the year in which they are usually grown is a subject beyond the scope of this publication. Those interested are directed to the reference material suggested in Section 112.

Amount of water required is roughly proportional to dry weight of crops

118. More water is required for the production of a ton of plant products than for half a ton—on the same soil and under similar growing conditions. Table 4 shows 5 acre-feet as the over-all water required for 5 tons of alfalfa hay. Experience also indicates that under the same conditions about 3 acre-feet would produce 3 tons.

Root zone should be kept moist throughout the active growing season

119. Speaking generally, the soil should be kept moist (above the wilting range) throughout the root zone during the active growing season. Some reduction may be allowed in the upper part of this zone during the maturing period. When the soil moisture in any part of the root zone drops below the wilting range, plant growth in that section is checked. When all sections of the root zone reach this condition the plant dies.

Knowledge of factors necessary in planning irrigation

120. To determine the amount of water which should be applied to his fields, the irrigator should examine his special set of conditions, interpret these in the light of known climate, soil, and plant facts, and apply the amount of water indicated. Furthermore, should the irrigator be a new hand, either at irrigation generally or on the land he is now using, it is suggested that a few holes with shovel or auger a few days after an irrigation would give him information on penetration, subbing, etc., which would be worth many times the effort.

When seeking information, he should specify the conditions mentioned above.

CROPPING SYSTEMS AND WATER EFFICIENCY

Diversified farming increases efficiency of water supply

121. Somewhat closely related to the subject, "Quantity of Water Required," is the one of the efficient use of the total supply available. This is a subject in itself and will be only briefly mentioned here. The reader will find an analysis of this feature

of water use in the mimeographed material entitled, "A Method of Balancing Irrigated Crop Acreages against Water Supply," by Charles Hobart (11).

Quite briefly, Mr. Hobart's findings are summarized in his statement, ". . . farmers should carefully balance cropping programs against water supplies." In support of his conclusion, the author presents figures which indicate the following results.

A continuously available supply of 100 miner's inches of water ($2\frac{1}{2}$ second-feet, or 1,125 gallons per minute) will service: A one-crop system of cotton growing—180 acres, or a one-crop system of alfalfa growing—257 acres, or a diversified cropping system, including:

Alfalfa	120 acres
Cotton	120 acres
Small grain.....	80 acres
Sorghum	40 acres
	—
Total.....	360 acres

Other cropping programs can be worked out which are in balance from the irrigation standpoint.

It will be noted that the diversified crop system increases the total area usable under the one-crop system from 180 acres for cotton or 257 acres for alfalfa to 360 acres for the diversified crops. The author also says: ". . . it is believed that not many years will pass before those acres [120 acres of cotton] will produce more cotton than 180 undiversified cotton acres." He adds, "In some undiversified areas—growing cotton for long periods of time—it has already been found necessary to use as high as 7 acre-feet to grow a cotton crop. This is twice what it should be if fertility is high."

IRRIGATION OF CROPS—FREQUENCY

HOW OFTEN SHOULD ONE IRRIGATE?

The frequency of irrigation, like the amount of water required, must be determined by a study of the factors involved rather than by rule.

Soil class important in determining irrigation frequency

122. An important factor in determining frequency is the class or kind of soil to be irrigated. In Figure 6, the sandy soil selected for illustration was shown to have but $\frac{3}{4}$ inch of plant-available water in each foot of root zone, while the loam had $1\frac{1}{2}$ inches and the clay $2\frac{1}{4}$ inches in the same root depth. Logically, therefore, plants growing on the sandy soils need more frequent irrigations than do those on the loams or the clays. Recall that these were special soils from their respective classes, but the general relationship holds as among the classes.

Frequent irrigations may be necessary for young plants

123. In the early life of plants, the factor illustrated in Figure 5 will apply. Here the dry sections within the small root zones should be rewet, even though the possible root feeding zones may still be fully moist. Roots dry only those soils in immediate contact with them.

Growth occurs only in soils above wilting range

124. When the root development is well advanced, irrigations should be so timed as to keep the moisture content of the zone of the working root depth safely above the wilting range. Otherwise, the growth of the plant will be seriously checked, even though plant life may be sustained by the few roots working on reserve moisture at the maximum root depths. Bear in mind also that roots grow to water; water does not move to roots.

Constantly saturated soil undesirable

125. Though only moist soils produce growth, the fact should be noted that a soil always saturated is a soil from which all air has been expelled—the soil pores are filled with water rather than with air and water—and air is necessary for root growth. Therefore, a soil-moisture condition which fluctuates between saturation and a point somewhat above the wilting range is the one most to be desired.

Saturated soils show long-time unfavorable effect

126. In actual practice, unfavorable results from too frequent irrigations do not show up in a single season's growth, or even, perhaps, in that of a number of seasons. An exception to this exists when high water tables are present, but the effect here is more likely to be due to root suffocation than to any impairment of the soil. The final result after a series of years is another matter and such a subject is outside the scope of this publication. Readers are referred to *General Bulletin 124, Citrus Chlorosis as Affected by Irrigation and Fertilizer Treatment*.

Too frequent irrigations of sandy soils waste fertility through the leaching process.

Plants form irrigation "habits"

127. Plants which have become accustomed to frequent irrigations (two or more times a week) will show wilt if the irrigations are suddenly timed to longer periods, even though there be plenty of moisture in the lower soil depths. Plant wilting a few days after a series of showers is a common illustration of this fact.

The explanation is probably that an excessive number of roots have been developed in the rich surface soil, and when this dries down a period of wilting occurs until the plant adjusts its growth to the new conditions. One should not take such wilting too seriously—the plants soon recover.

Morning wilting a sign of water stress

128. Generally speaking, when plants wilt early in the day, do not recover at night, or show a very dark shade of green in color an irrigation is needed. The best growth is secured when moisture is available to a large proportion of the roots at all times, which means that at least most of the root zone remains above the wilting range during all the active growing period.

Knowledge of facts best for determining frequency

129. Rather than suggest time periods for irrigations—for conditions as varied as they are in Arizona—it is advised that the inexperienced irrigator seek this information for his own particular case. The source may be farmers or agencies who have learned effective methods from experience or studied observation. One should be careful to determine that the conditions are similar in all essential respects. But an even better way is to learn from a knowledge of soil, water, and plant facts what results should be expected and then to find out by the aid of the shovel and scales the results actually being secured. The shovel will tell one the moisture conditions in the soil, and the scales will remove guesswork from yield estimates.

Factors affecting quantity affect frequency

130. Other factors influencing the frequency of irrigations are all those listed under "Irrigation of Crops—Quantity" as affecting the amount of water required. All factors affecting the amount of water needed will also influence the frequency of irrigations, especially in the matter of heavy or light applications. Plant requirements is the determining factor.

Soil, water, plant facts determine frequency

131. In considering frequency, a number of facts should be kept in mind. These are briefly summed up:

1. Young plants with limited root systems need less water, but they need it more frequently than do older plants with fully developed root systems.
2. Good soil sanitation requires some variation in the water content of the soil.
3. Soil below the wilting range produces no growth.
4. Plants form irrigation habits.
5. Sandy soils require irrigation more frequently than do heavier soils.
6. Since the largest amount of readily available fertility is in the surface foot of soil, growth—especially foliage growth—is most rapid when this section is moist.
7. A fertile soil requires less water per pound of product than an infertile soil.

8. The amount of water actually used by a plant is roughly proportionate to the plant's leaf area.
9. Zones of maximum root activity do not long remain close to the main stem or trunk of the plant but tend to move toward the outer drip of the branches. This fact is more noticeable in the case of trees and perennials generally (Fig. 18).
10. Some plants, like most vegetables where quick and succulent growth is desired, respond favorably to a rather high and constant moisture content in the surface foot—where available fertility is most abundant.
11. Frequent irrigations tend to waste water through excessive surface evaporation. Harris (6) estimates a water loss from each irrigation of from $\frac{1}{2}$ to 1 acre-inch, because of surface evaporation.
12. Frequent light irrigations fail to develop an efficient root system or to make an efficient use either of the soil or of the water applied.
13. If before planting the soil has been wet to a normal root-zone depth, the frequent light irrigation method can be more effective than it would otherwise be.

IRRIGATING THE ORCHARD AND GARDEN

BY HARVEY F. TATE*

The principles underlying successful irrigation of orchards and gardens are much the same as those relating to field crops. The difference, if any, is that the application of these principles must be more carefully made. This is true for the reason that as a rule the land used is more expensive, carries a higher degree of fertility, produces a more delicate type of crop, and frequently is irrigated with more expensive water.

Such conditions demand much attention to detail so that losses may be kept at a minimum.

Roots grow mostly at or near their tips

132. As stated elsewhere in this publication, the type of root system has much to do with determining the details of irrigation practice. Generally speaking, the roots of fruit trees have both depth and spread, and as stated by Weaver (1),

Absorption (water and plant food) may occur throughout the entire extent of the root, but takes place most actively in the younger and usually deeper parts—only the less conspicuous and younger portions of the root system are really active in absorption. The older parts have the walls of their exterior cells more or less thoroughly water proofed, and their functions are almost entirely those of anchorage, transport and storage.

The practical application of the facts stated by Weaver is illustrated in Figure 18. The conclusion is that the root zone needing

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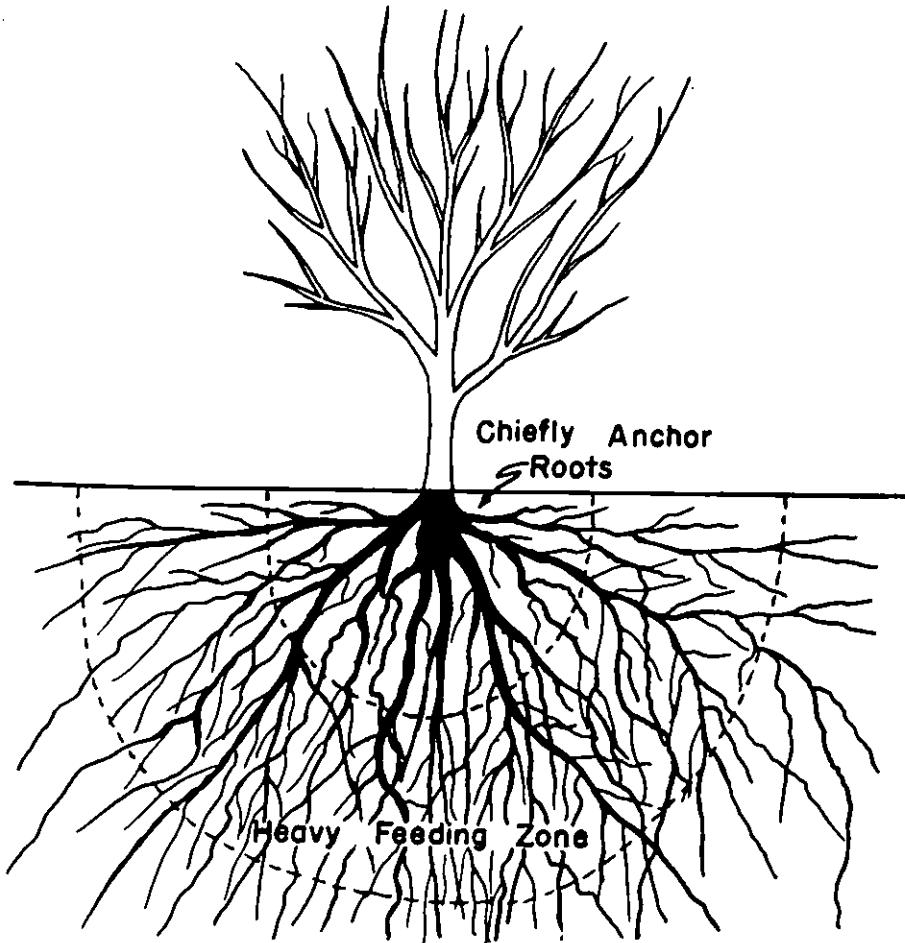


Figure 18.—Root-feeding zones.

water most frequently or in greatest amount is located some distance below the surface and some distance away from the main trunk. This of course must not be interpreted as meaning that the area close to the trunk has no feeding roots, but merely that the outer and lower areas have more.

Close furrows insure efficient subbing

133. In order that the irrigation water may reach the part of the root zone desired, strict attention must be paid to the movement of water in the soil, especially its lateral or subbing movement.

As illustrated in Figures 9 and 10, different soil conditions show widely differing subbing results. Practices must therefore be so arranged as to insure the distribution desired. This photograph of an actual field condition illustrates one method of securing a complete wetting of the entire possible root zone. Note that the



Plate III.—Citrus orchard, showing close furrows and complete subbing effects.

water furrows are close together and occupy all the distance between the tree rows; there are no dry zones.

Vegetable root systems differ in extent

134. Since root growth should determine the volume of soil to be wet, Table 5, Root Depths of Vegetables, is presented on page 51. Soil and water conditions determine the extent to which such root growths are practical. It is not intended to intimate that root systems must have the extent shown in the table, but only that these are the normal feeding depths when soil conditions are favorable.

Subbing conditions in the garden need careful checkings

135. Finally, the truck grower must realize that he is dealing with small seeds and small plants and that it will be a serious mistake to *assume* too much subbing. There is no practical means of calculating how far the irrigation water will sub from the furrow; the distance will be governed largely by the resistance which the water meets in moving downward. The only safe plan is to examine the soil some hours after an irrigation. The wetted sections below the furrows should meet—not only at the surface, but down to the depth of the root zone (Fig. 9).

Water more efficiently used by fertile than by nonfertile soil

136. In support of the statement that a rich soil makes a more efficient use of water than the same soil when poor, we may quote

from Keissel (9) to the effect that corn grown under controlled conditions showed a reduction of 28.9 per cent when manure was added to an infertile soil and a reduction of 8.1 per cent when manure was added to an already fertile soil.

Etcheverry (10), discussing this same subject, presents figures of pot tests indicating that when manure was added to a soil the amount of water required per pound of dry matter produced was reduced 16.3 per cent, and when a nitrate of soda was added the water reduction was 24.3 per cent.

Hobart (11) reports a water efficiency for cotton on a worn-down soil of about one half that which should exist on a soil of good tilth and fertility.

Two acre-feet of water on a fertile soil produce as much crop tonnage as 3 acre-feet on the same soil which is nonfertile.

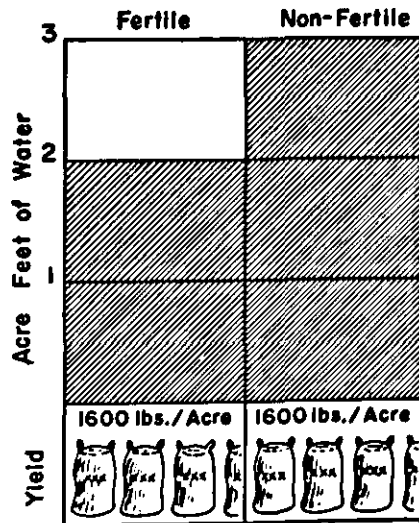


Figure 19.—Fertile vs. nonfertile soil.

TABLE 5.—ROOT DEPTHS OF VEGETABLE PLANTS

Shallow-rooted (to 2 ft.)	Moderately deep-rooted (to 4 ft.)	Deep-rooted (to 6 ft.)
Broccoli, sprouting Brussels sprouts Cabbage Cauliflower Celery Corn, sweet Lettuce Onions Potatoes, Irish Radishes Spinach	Beans, bush Beans, pole Beets Carrots Chard Cucumbers Eggplant Mustard Peas Peppers Squash, summer Turnips	Artichoke Asparagus Beans, lima Cantaloupes Parsnips Pumpkins Squash, winter Sweet potatoes Tomatoes Watermelons

DICTIONARY OF TERMS

Term	Used with reference to	Definition (Numbers refer to sections, where the term is used and further discussed)
Adhesion	Soil and water	The force holding like particles together. 20
Aggregates (see crumbs and granules)	Soil particles	A cluster of soil particles cemented together. 12, 14, 18, 97
Agricultural	Soils	Suitable for agricultural purposes.
Alkali	Soil and water	Containing soluble alkali salts. 61-64, 72 (4)
Alkaline or alkali	Soil and water	Not acid: pH above 7.3. 72 (3), chart, Fig. 21
Border	Land	The space between border ridges.
Border effect	Land and growth	The best growth appearing on border ridges. 94
Capillarity	Water movement	The subbing movement from thicker to thinner water films. 20, 55, 56
Carbonic acid	Soils	A product of decaying organic matter, a weak acid. 97
Class	Soil	A classification of soils based on size of soil particles, sand silt, or clay and the proportion of each. 10
Clay	Soil	The smallest particle group; has cementing properties. 10, 12
Cohesion	Soil and water	The force holding unlike particles together. 20
Crumbs (see granules and aggregates)	Soil	Clusters of soil particles; same as aggregates or granules. 12
Deflocculate	Soil	See dispersion. 72 (7)
Disintegrated	Rocks and soil	Broken into smaller pieces by natural forces.
Dispersion	Soils	Breaking soil crumbs into their original particles—sand, silt, and clay. 12-14
Field water holding capacity	Soils	The water held by the soil against the forces of gravity and capillarity; stored water. 23, Fig. 3, 50, 51
Films	Water	The very thin water coating around soil, particles and crumbs. 21-23
Flocculate	Soil	To combine soil particles into crumbs or aggregates. 72 (6)
Four-fifths zone (4/5 zone)	Land and irrigation	A local term indicating a shallower penetration on the section of border composing its four-fifths area. 88, 89, Figs. 12 and 13

Freeze up	Soils	To become too tight to take water, as dispersed soils. 96
Good working condition	Soil	A farm-used term describing the moisture condition of a soil when dry enough to work. It will crumble on pressure after compacting. 80 (3)
Granulated	Soils	Having many granules or soil clusters or crumbs. 14
Granules	Soils	See aggregates or crumbs. 12
Gypsum	Soil amendments	A calcium sulphate compound used to correct a black alkali condition. 98
Head	Water	The quantity of water flowing in a stated unit of time. 105, and p. 80
Leaching	Soil	Dissolving and washing salts to lower levels in the soil. 9, 126
Loams	Soils	A mixture of sand, silt, and clay in such proportions that the properties of none of these dominate. 10, 17
Maximum depth	Roots	The greatest depth to which any of the roots reach. 34
Middle zone	Soil below surface	A popular term, designating a portion of the root zone below a surface zone but above the lowest depths. 92
Moisture equivalent	Soil	A laboratory measurement of the field-holding capacity of a soil. 46, footnote 2
Organic material	Soils	All materials which are the product of animal or vegetable growth. 14, 19, 84, 97
Particles	Soils	The original soil units which combine to make crumbs, sand, silt, and clay. 10
Penetration	Roots	The growth of roots in any direction in the soil. 34
Penetration	Water	Usually used to denote the movement of water downward in the soil. 86 and chapter on penetration
Perched	Water tables	Water held up or pooled by reason of tight soil layers. Figure 10
pH (pronounced p, h.)	Soil and water	A measure of the acidity or alkalinity of a soil. 72 (3)
Plant available	Water and roots	Water which the plant roots are able to absorb. 26, 27
Profile	Soil below surface	A cross section of soil showing the various zones or layers exposed, usually to a depth of 6 feet. Fig. 20
Refill	Soils	To replace soil water which has been lost by plant-root absorption and surface evaporation. 29, Fig. 6
Refill requirements	Water	The amount of water required to refill a given depth of soil. 29, Fig. 6

Sand	Soils	The coarsest of the three soil separates; or a soil having less than 20 per cent of silt and clay. 10, 15
Saturated	Soils and water	Soil having a water content well above the field-holding capacity—pore spaces filled with water. Figs. 2 and 8
Separates (see particles)	Soils	Same as particles—smallest soil units. 10
Silt	Soils	The middle-sized group of soil separates. 10
Silting-up	Soils and water	The washing and settling of silt and clay particles into the pore spaces of soil. 94, Fig. 14
Stationary	Water	Water held too firmly by the soil particles to be removed by gravity or capillarity. 23, 50, 51, Figs. 3 and 8
Structure	Soils	The arrangement of soil particles, as dispersed, aggregated, etc. 18
Subbing	Water	The movement of soil water by capillarity, not gravity; a creeping movement. See capillarity. 20, 53, 54, 56
Sulphur	Soil amendment	Used as a corrective for black alkali soils. 98
Texture	Soils	The proportion of the soil separates or particles. See class. 18
Time-period	Irrigation	The length of time water is on the surface of any ground. 87, 88, 89
Transpiration	Plants	The breathing process of plant leaves. 112
Type	Soil	A group of soils having a common origin and similar profile characteristics, such as texture, structure, drainage, etc. 18
Uniform	Soil profile	A soil having the same texture and structure to a specific depth—usually 6 feet. 53
Uniform rate of absorption	Soil water	A soil condition allowing the same rate of water penetration. Figs. 9, 10, 53
Vapor movement	Moisture in soils	The movement of soil moisture in the form of vapor or gas (steam). 51
Water table	Soil and water	A body of pooled water below the surface, held up by a tight soil layer. Fig. 10
Wilting point or wilting point range	Soil and plants	The moisture content of soils at which plants wilt; plants cannot reduce the moisture content below this point or range. 27
Working depth	Roots	The soil zone in which the roots are most abundant and most active. 34
Zone	Soil profile	A layer of soil, variable thickness, differing from the adjacent soil layers in one or more respects. Fig. 20

APPENDIX

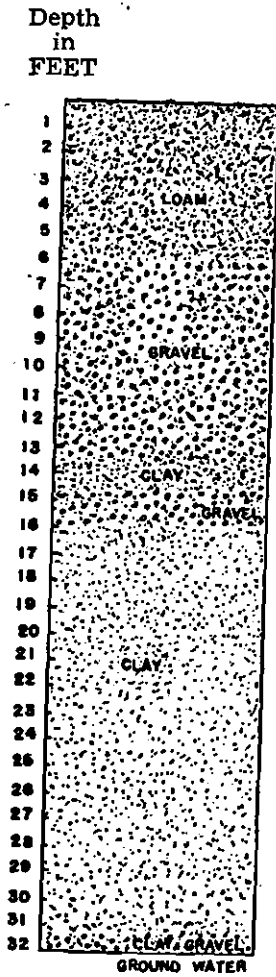


Figure 20.—A 32-foot soil profile.

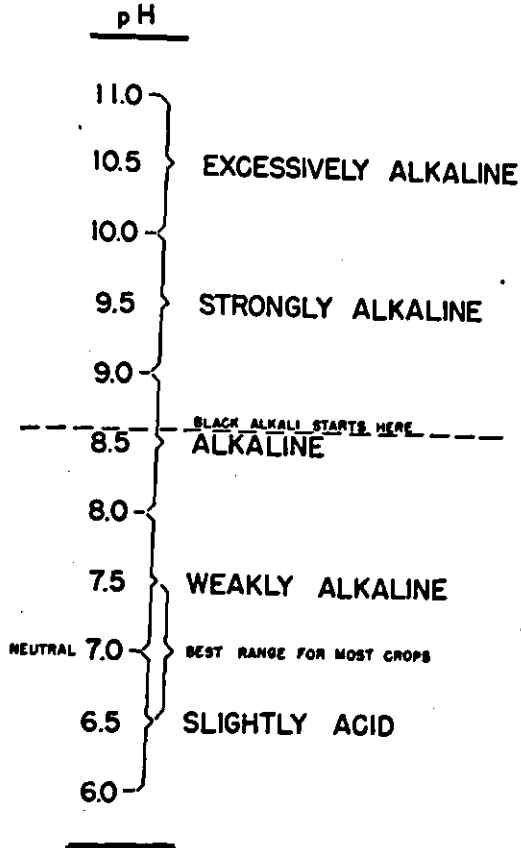


Figure 21.

Figure 20 illustrates a rather common soil profile. It is from an actual drawing of conditions shown by excavation on the old date farm near Alhambra, once owned by the University. The drawings were made by Alfred J. McClatchie and are carried in *University of Arizona Bulletin 37*.

Figure 21 is a chart showing pH readings as determined in the laboratory and the relation of these readings to the conditions of acidity or alkalinity which actually exist in the soil tested. The chart is copied from *Extension Circular 108*.

NOTE.—The drawings on page 34 are presented through the courtesy of Karl Harris (6).

In section 89, page 33, read "Figures 12 and 13."

A SUMMARY

This publication is, in itself, a summary of the principles of irrigation practice, and the facts are further summarized in the bold-faced section headings. The reader will find that these headings, read consecutively, form a connected story of the subject.

ACKNOWLEDGEMENTS

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UNITS OF WATER MEASUREMENT AND DEFINITIONS

The following units of measurement and definitions are of interest to all water users.

UNITS OF VOLUME

1 acre land = 43,560 square feet

1 acre-foot = the quantity of water required to cover 1 acre of land 1 foot deep

1 acre-foot = 43,560 cubic feet of water

1 acre-foot = 325,850 gallons

1 acre-inch = the quantity of water required to cover 1 acre of land 1 inch deep

RATES OF FLOW

1 cubic foot of water per second = 1 second-foot

1 second-foot = 450* gallons per minute

1 second-foot = 40 miner's inches (statutory law in Arizona)

1 second-foot = 7.5* gallons per second

1 miner's inch = 11.2 gallons per minute

MISCELLANEOUS

1 second-foot flowing 12 hours = 1 acre-foot*

1 second-foot flowing 1 hour = 1 acre-inch*

450 gallons per minute for 1 hour = 1 acre-inch

40 miner's inches for 1 hour = 1 acre-inch

1 acre-foot provides:

a 3-inch irrigation for 4 acres

a 4-inch irrigation for 3 acres

a 6-inch irrigation for 2 acres

To convert second-feet to acre-feet per day, multiply by 1.984.

To convert acre-feet to gallons, multiply by 43,560 and then by 7.5.

*Approximate amounts for convenience of conversion.