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IRRIGATION IN FRUIT GROWING.

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U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., February 15, 1900.

SIR: I have the honor to transmit herewith a paper on irrigation in fruit growing, by E. J. Wickson, M. A., professor of agricultural practice in the University of California and horticulturist of the California Agricultural Experiment Station, prepared under the supervision of Prof. Elwood Mead, irrigation expert in charge of the irrigation investigations of this Office, and to recommend its publication as a Farmers' Bulletin of the Department.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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IRRIGATION IN FRUIT GROWING.

INTRODUCTION.

Throughout a considerable area of the United States irrigation is indispensable to the growth of fruit. Throughout a greater area irrigation is essential to the growth of fruit of the highest quality and market value. Throughout a still greater area the availability of irrigation is a surety against occasional losses of crops and injury to trees and vines through drought. There are no data for accurate definition of these particular areas, but it is a fact, never so generally appreciated as at the present time, that the fruit grower in all except a few of the most humid regions of the country may look upon a water supply, available for use when desirable, as an element of great value and an assurance of safety in his business enterprise. Evidently the so-called "arid West" is no longer to stand alone in proclaiming the advantage of irrigation. Wherever fruit crops were injured or lost by the long drought of the summer of 1899, there may be found testimony of the benefit which would have accrued if the grower had been ready to regulate his soil moisture by irrigation. For this reason the art of irrigation is becoming far more than a sectional question in this country, and the knowledge of it which has been gained by a half century of experience in one section becomes of direct practical advantage in nearly all sections. The time has come when fruit growers everywhere must understand the elementary facts, at least, of the relation of irrigation to fruit production and of the development, distribution, and use of water in horticultural enterprises.

It should be an inspiring reflection to an American that he need not seek abroad for the best irrigation methods in the growth of fruits. The irrigation pioneers of the far West ransacked the whole Mediterranean region of Europe and Africa and farther India for example and suggestion and found little which American insight and ingenuity could not improve. The result has been that during the last decade commissioners from nearly all governments having possessions suitable for fruit production have made personal examination of American methods and have commended them for superior capacity and efficiency. It is not contended that America has the greatest irrigation enterprises of the world. Such comparison is beyond the scope of this writing. But for irrigation enterprises as applied to the growth of fruit, it is claimed that there are none so great nor so rationally and effectively methodized as those of this country. For all these reasons it is thought that the farmers and fruit growers of the United States may be interested in a general statement, in as compact a form as possible, of the relations of irrigation to fruit production, and of irrigation methods, as they have been demonstrated by Pacific coast experience, to the end that recourse to irrigation, wherever it be found desirable, may be facilitated and promoted.

IRRIGATION WITHOUT CULTIVATION.

A brief historical illustration is instructive, as showing how conceptions of the necessity and desirability of irrigation in fruit growing may change and how ill placed is any prejudice for or against irrigation as such. The Spanish missionaries who entered California from Mexico in 1769 established fruit gardens and vineyards with irrigation facilities at about fifteen points along about four hundred miles of the coast region of the State. They laid off their plantations in old Spanish style and proceeded upon the assumption that fruit could not be grown in California without irrigation. The few adventurers, sailors, and trappers who came to the State from all countries during the first half of this century accepted the missionary view of the case, and most of them, having neither energy nor ambition to develop and distribute water, lived upon beef and beans with such occasional indulgences in wine and fruits as they could get from the missions. There were a few who emulated the example of the padres, but were content to accept their methods of frequently running water through permanent ditches to the uncultivated orchard or vineyard. This was the first conception of irrigation as essential to the growth of fruits in a country with a rainless summer.

CULTIVATION WITHOUT IRRIGATION.

Soon after the gold discovery and the arrival of Americans in multitude, it was seen that tillage of the surface soil prevented evaporation to such an extent that fruit trees and vines could make great growth and bear heavily with such moisture as was conserved in the soil from the rainfall of the wet season. It was a great surprise that trees could do this even though no rain fell for several months, and a sharp reaction from the old Spanish conception of constant irrigation resulted. It was then claimed that irrigation was unnecessary and that thorough surface cultivation during the dry season would produce better fruit than irrigation. This was the second conception, viz, that irrigation was not only not essential, but was an injury to fruit even in a country with a rainless summer, and that regions which would produce fruit without irrigation enjoyed a very superior natural endowment which could hardly be overestimated. For many years the conflict between the advocates of irrigation and nonirrigation continued. Meantime experience was teaching valuable lessons. It was found that in some soils and situations the nonirrigation policy failed to secure satisfactory crops of good fruit and that a properly regulated irrigation practice succeeded in doing it. It has required nearly a quarter of a century of trial and discussion to arrive at the true, rational, and practical demonstration of the matter, which is that an ample moisture supply, available all through the growing season, is necessary to the best work of the fruit tree or vine, without regard to whether that moisture comes from rainfall or irrigation; that irrigation or nonirrigation may be either right or wrong according to the conditions of soil or season or rainfall or the kind of tree. They may be both right and wrong in the same locality in the same month. The long process of inquiry, experiment, and observation by which this conclusion was reached involves propositions of universal applicability, the demonstration of which is of importance to operators in both arid and humid regions and affords a motive for the present discussion.

IRRIGATION AND CULTIVATION, AND THEIR MUTUAL RELATIONS.

The issue between irrigation and cultivation arose at the very beginning of systematic fruit growing in California, as has just been suggested. No adequate understanding of the tillage principles involved was then exhibited; the empirical discovery of the facts was a surprise; the quick and wide use of the facts constitutes one of many striking illustrations of the versatility of the American mind in dealing with the strange phenomena of an arid region, which has marked the advancement of California agriculture. The experience of California fruit growers in the matter of tillage as related to moisture conservation and to stimulation of plant growth affords unique and emphatic illustration of the principles laid down by our best writers on these subjects. As these writings are readily accessible, attention will be paid rather to the effectiveness of proper cultural methods, as learned by experience, which are widely applicable, even beyond the arid region in which they have secured adoption.

Common observation showed at the beginning that fruit trees and vines, if well planted during their dormancy in the wet season, would make a fine growth in the spring and continue it during the early part of the dry season, but would suffer, and in some cases actually perish as the dry season advanced, because the soil would become so dry to a depth of several feet that the root hairs would die and continued evaporation from the leaf surface would extract every particle of moisture from branch and root and destroy the young tree. If the soil were heavy, it became as hard as a rock, so that a post hole could be dug only with a crowbar; if it were light, it would lose all adhesiveness and become either ashy or sandy. In both cases the soil would become not only dry, but hot, and incapable of maintaining plant growth. On the other hand, in places only a short distance away, on the same soils, where the surface had been mellowed after the late rains had compacted the surface, directly opposite behavior of the plants was seen; growth was continued in good form and color, fruit was carried to astonishing size, and the trees and vines were thrifty and vigorous during months of cloudless skies, hot sunshine, and dry air. The suggestion of such a contrast was speedily made use of, and the discovery that better fruit could be grown by surface tillage than by the old Spanish practice of frequently running water over the hard surface was hailed with enthusiasm.

CULTIVATION AS A RELIEF FROM IRRIGATION.

From this early announcement of the efficacy of tillage of orchard and vineyard the resort to plow and cultivator became general, and nearly half a century of experience justifies the conclusion that adequate cultivation obviates the necessity of irrigation, providing (1) there is sufficient rainfall or underflow at any season to support a year's growth and fruitage; (2) there is sufficient retentiveness in the soil to hold water from evaporation or leaching; (3) there is sufficient depth of soil to constitute a reservoir of adequate capacity. Soil and moisture conditions are of universal occurrence, and are therefore worthy of consideration wherever fruits are grown, and the understanding of them may be very helpful to those who are beginning in new regions, and in many cases suggestive of new methods and policies in older regions. It is important that we define them.

Adequate cultivation.—This has reference both to water reception and water conservation. Wherever the rainfall is liable to come in heavy downpours there is great danger of loss by what has been called the "run off." This will vary according to the nature of the soil and the local topography, but even under the most favorable conditions it is a great loss unless the rains are very gentle and occur at intervals. When the soil is hard and compacted at the surface it acts as a roof and sheds almost all of the water into the drainage channels. The writer has seen instances in which rainfall enough to send moisture to a depth of several feet has penetrated only a few inches. Adequate cultivation begins, then, with the opening of the surface for water reception, and unless this is done the game is stopped at its beginning. The subsoil reservoir will never be filled unless the cover is porous by nature or rendered so by coarse tillage at the beginning of the rainy season.

Adequate cultivation for water retention means such treatment of the surface after the rains have fallen as will reduce evaporation to a minimum. A compact surface layer is not only slow to receive water from above; it is also quick to lose it by surface evaporation as it rises progressively from below. The result of this loss is the deep drying which is destructive first to root hairs and finally to the whole plant. A loose surface layer prevents this escape of the moisture into the air and increases in effectiveness as the soil is more and more finely pulverized and as the loose layer becomes deeper. Cultivation, then, to retain moisture for the use of the roots of trees and vines during the dry season consists in maintaining a deeply pulverized surface. To secure such a surfaçe pulverizing once is not enough; even though no rain may fall, the surface will become recompacted and must be repulverized. In a soil thus treated moisture is always present quite near the surface, and so great is the contrast between this and the deep dryness of an uncultivated soil that the impression currently prevailed that cultivation produced moisture. It does not produce it; it merely prevents its loss by surface evaporation.

Adequate moisture.—Evidently this condition is fulfilled when the natural moisture thus faithfully conserved is enough for the season's needs of the tree or vine. This moisture may come from rainfall on the particular area or from rainfall supplemented by underflow from adjacent catchment areas. How can it be told when there is enough? The experience of the arid region is that this can not be answered by measurement of rainfall. There are many places where an annual rainfall of less than 20 inches is adequate for the full growth and fruitage of the tree; there are other places where twice and even thrice that amount will not obviate the necessity of summer irrigation. The test of the matter is the behavior of the tree during its full cycle of growth and fruitage.

Retentive soil.—Another condition which will render adequate cultivation effective or not is the mechanical character of the soil. The soil must contain enough fine particles to make it hold water well. Excessive fineness makes adequate cultivation difficult; excessive coarseness makes cultivation ineffective; that is, the soil will dry out in spite of it, both by evaporation and drainage. The ideal fruit soil is a loam, because it is coarse enough to be cultivated readily and fine enough to prevent the too free access of air and to prevent the too rapid descent of water by gravity. This favorable condition between coarseness and fineness is prevalent among the predominating light loams of the arid region, in the alluvial soils of the river banks, ancient and recent, and in many of the upland soils resulting from the decomposition of the country rocks. It is the highest type of soil for almost every cultural purpose, and it meets its highest use, perhaps, in the growth of horticultural products, because they command highest values.

Deep soil.—The third condition essential to the highest effectiveness of adequate cultivation in the production of fruits is a deep soil. This is the direction in which the soils of the arid regions are uniquely eminent and the full significance of soil depth is only now coming to be recognized. Rich, deep soils have been prescribed for fruits from time immemorial, but formerly this conception proceeded chiefly upon the vast amount of plant food thus rendered available. Depth as a condition of water holding is not less important. In fact, in proceeding by cultivation to escape irrigation, water holding is the ruling function, because any amount of plant food is useless without adequate moisture to render it available. It is proper to think of a deep soil as a great subterranean reservoir as well as a great storehouse of plant food. Into this reservoir the water sinks through the surface, roughly broken at the beginning of the wet season, passing to the lower strata so readily that large downpours are quickly absorbed and a large volume of water is thus taken below for the use of the trees during the following summer. The surface, by the coarseness of the soil particles, is kept from puddling, and can be replowed or cultivated during the wet season if desirable to prevent too rank a growth of weeds, or to turn under a green manure crop. In such a deep soil trees and vines root deeply, a penetration of 20 to 30 feet in soils free and fertile to that depth having been repeatedly noticed in well digging. With such an available water supply perfect cultivation to prevent loss by surface evaporation will enable trees and vines to proceed through a growing and fruiting season covering half the year without a drop of rain, always manifesting the fullest thrift and vigor. In fact, in some parts of the Pacific coast where the winter rainfall is unusually heavy and fall frosts sharpest cultivation has to be stopped late in the summer to allow a certain amount of drying of the soil to induce the tree to stop its extension and mature its wood seasonably. On the other hand, in other parts of the coast with less rainfall and with less danger of frosts the cultivation cover of the soil reservoir is maintained until the opening of the succeeding rainy season to support late growth and to carry over a part of the conserved moisture to protect the trees in case the following year's rainfall should be scant. In this deep-soil storage of water lies the secret of the drought endurance of trees in the arid region. They are prepared for drought by deep rooting in a protected reservoir of moisture. The contrast is seen in the behavior of trees on uncultivated shallow soils in the humid regions of this country and Europe, where a few weeks of drought destroys vast values in fruit crops and cripples the trees for following years. There are instances in abundance also in the arid region where the soils are not deep enough to form such a reservoir as has been described. For these reasons cultivation can not always guarantee the thrift and success of the tree, but unquestionably in orchards which have been kept as pasture fields, or where very slack cultivation has been practiced, there are many instances of deep soils which have not been able to discharge their proper function in supporting the summer thrift and fruiting of trees because their reservoir cover has never been opened to receive the full rainfall, and is never closed to retain such part of it as they did receive. In many places, therefore, cultivation may completely remove the necessity of irrigation.

WHEN IS IRRIGATION DESIRABLE?

Obviously, when the best work for moisture reception and retention is done by the fruit grower and still the tree shows distress during drought and becomes irregular in bearing in regions to which it is well suited, or when the fruit is not of satisfactory size and quality even when the trees are properly pruned and thinned, it is usually desirable to secure irrigation to supplement the natural moisture supply. This assumes that the study of the behavior of the tree is the best guide to an understanding of its needs. This is plainly the conclusion to be drawn from long experience in Western irrigated regions. While it is perfectly true that there is a direct relation between the normal rainfall and the need of irrigation, and the general prevalence of irrigation may, to a certain extent, be mapped upon the curves of least rainfall, it is also true that large rainfalls do not necessarily free a locality from the necessity of irrigation. This fact has been foreshadowed in the discussion of cultivation. If it should appear that a normal rainfall of 15 inches is enough to assure the profitableness of deciduous fruits in some valleys, it would not be safe to assume that 40 or even 50 inches would preclude the necessity of irrigation in others. As a matter of fact, a rainfall of 40 inches might destroy many fruit trees on a level stretch of heavy soil by long submergence of their roots in some places, while 40 inches in another place, poured upon a shallow, unretentive soil, might not bring an early peach to perfection. It is therefore unsafe to write an irrigation prescription upon a rainfall record. Reasonable accuracy could be secured by a formula which includes rainfall, soil, slope, depth, and character, summer temperature, and atmospheric humidity, and the age and character of the tree; but this would involve wearisome computations. Moreover, all theoretical forecasts based upon computed moisture requirements and local rainfall are apt to include wide errors. The study of the tree and its fruit is most satisfactory, to the practical fruit grower at least.

From wide observations in many regions for many years it is possible to mention the following as fundamental facts:

(1) There are wide differences in the moisture requirements, not only of the different kinds of fruit trees, but of the early and late varieties of the same fruit.

(2) Trees of the citrus family require much more water than those which drop their leaves during a part of the year.

(3) But all evergreen fruit trees do not require more water than all deciduous fruit trees; for example, the olive will bear well with less water than is required by a peach; still, satisfactory olives must not be expected unless the tree has what it needs for free growth.

(4) The needs of all trees are conditioned upon their age and work. A moisture supply which may bring satisfactory growth to young trees may not enable the same trees to bear regularly and profitably.

(5) Shallow-rooting fruit plants, even if well cultivated, may perish during a drought which will have no evil effect upon fruit trees and vines on the same soil, because of the deep rooting of the latter.

Evidently, then, conclusions as to the desirability of irrigation must be drawn with due knowledge of the general requirements of the growth contemplated, as well as character of the land to be planted; but there are specific needs of the tree pertaining to its different phases of growth and fruiting which are also involved in the question of when irrigation is desirable. Long observation of these phenomena in a region where there has been extended practice both with and without irrigation may yield some facts, widely significant, of moisture requirement, as learned by practice, to compare with the conclusions reached by systematic experimentation.

EFFECTS OF INSUFFICIENT MOISTURE.

POOR GROWTH.

This could be passed as an obvious suggestion were it not that so many fail to recognize in a lack of moisture the cause of evil manifestations which they try to explain otherwise. Tree tonics and fertilizers, fungicides, sometimes even insecticides, are applied to trees which are simply famishing for water. Even young trees will show too light a color, or the outer edge of the leaf will die, or the young shoots will die back, not for lack of plant food nor through the action of any blight or disease, but because the root hairs have dried off. This has already been mentioned as a result of lack of cultivation. It also occurs with the best of cultivation when there is no moisture to be conserved by it. Die back may result from any injury to the root hairs; it may be caused by excess of water in the soil as well as the lack of it. Whenever the appearance comes to leaf or shoot, the moisture condition of the soil should be first learned by deep digging, and when the spade strikes the hard, dry layer or when it throws out dust a good soaking of the soil should be given. In many cases the surface may be mellow and moist and the subsoil dry.

Experienced growers soon come to recognize the signs of distress in a famishing tree. Small leaves and short and thin wood growth are plain indications. But there may be enough moisture early in the season to enable the tree to escape these. In midsummer the leaves may lose their normal aspect and be slightly curved, limp, and, as it were, listless. Fading and wilting will ensue unless moisture be supplied. Water should be given before these signs of acute distress appear.

POOR FRUIT.

The bearing tree, as stated, may fail where a young tree making only wood growth may do well. There may be ample moisture early in the summer so that a good crop of fruit may set and new wood be formed, but moisture may be scant later when the tree needs it in generous amount to fill out the fruit and give it proper flavor and aroma. Even though the burden of the tree be reduced by proper pruning and thinning, it may still, for lack of moisture, bear only small, tough, and ill-flavored fruit. The preventive for this is irrigation applied in advance of the need. Such a check to growth can not be wholly cured.

INTERMITTENT BEARING.

Lack of moisture may prevent bearing the following year. The full annual duty of the tree is to perfect its fruit and to prepare for the next year's crop. A continuous moisture supply is necessary to maintain activity in the tree until this is accomplished. The tree will make a large draft upon soil moisture while making new wood and large fruit, and if moisture fails then it may be forced into dormancy before it can finish good strong fruit buds for the following bloom. If the distress be great the bloom may be scant or even fail to appear at all; if it be less there may be full bloom, but too weak to set the fruit well and no crop will be borne. Relieved of its fruiting, the tree will make new wood and fruit buds for the following year. Thus the tree, owing to partial moisture supply, forms the habit of bearing in alternate years. Though this habit may also result from other conditions as well, it is a fact amply demonstrated by experience in the arid region that insufficient moisture supply, even in rich soils and with the best care of the tree, will cause this undesirable alternation of bearing and nonbearing, and that however good other conditions may be, regular and satisfactory bearing can be assured only by the presence of adequate moisture.

Any of the foregoing appearances and behaviors of the tree are indications of the desirability of irrigation at some time and in some amount, and to secure the best results from fruit growing they should all be anticipated and prevented. Evidently they do not all pertain alone to what are known as irrigated regions, but they are at times encountered by growers everywhere. At present we have no adequate idea of how much is lost, even in the regions of summer rains, by irregular and intermittent moisture supply of fruit-bearing trees and vines. Great as these losses undoubtedly are they are capable of prevention along the lines of practice which have been learned by experience in the arid regions.

WHEN SHALL WATER BE APPLIED?

Evidently water should be applied in advance of any suffering by the tree. It is a mistake to allow the tree to fall into distress and then seek suddenly to relieve it. One advantage of irrigation is that it may save the tree from unseasonable efforts which result in irregular growth, untimely blooming, etc., as has been previously mentioned. It is usually too late to apply water to the best advantage after the tree shows the need of it; its needs should be anticipated.

WINTER IRRIGATION.

In the warmer parts of the arid region, where there is proper character and sufficient depth of soil to constitute the great subsoil reservoir previously described, it is possible to insure the deciduous tree all the moisture it needs for months by free winter irrigation which fills this reservoir just as a heavy winter rainfall could do it. There has been abundant evidence ever since the beginning of irrigation by Americans in California that such irrigation, followed by good summer cultivation, will be effective if the soil is retentive enough. Recent experiment in Arizona has approved for that region the teachings of experience in California. While the deciduous tree is dormant large amounts of water can be safely applied on all, except, perhaps, heavy clay soils, and water may be used at a temperature which would certainly be too cold to use while the tree is in active growth. For winter irrigation free application at intervals sufficiently long to allow deep penetration of the moisture is necessary.

SUMMER IRRIGATION.

When the use of water shall begin during the growing season depends, of course, upon the character and depth of the soil and the needs of the particular growth. The same considerations already urged to determine whether irrigation is needed at all have a bearing upon this question, because earliness of application is merely a degree of that need. Under some conditions, such as exceptional drought in the arid region, it may be necessary to irrigate to maintain the spring growth, and thereafter at intervals of about a month during the whole summer. Usually, however, there is natural moisture enough to start growth, even in the driest regions, and irrigation is first called for to give proper size and quality to the early ripening varieties, and from that on at intervals for the maintenance of growth, the perfection of later varieties, etc. This is in a region in which full irrigation is required.

Partial irrigation is now largely employed as a supplement to rainfall in other regions where the need of irrigation for deciduous fruit trees was formerly scouted. It varies in method according to local moisture needs.

Irrigation before fruit ripening is given in a single application of about 3 acre-inches per acre after the early ripening fruits have reached good size and just before they begin the final swell which determines size. This reaches the circulation of the tree in time to materially aid in the attainment of satisfactory size. In some cases this not only does this but enables the tree to hold its foliage and growth the balance of the season.

Irrigation after fruit picking is practiced where the moisture from rainfall is enough to properly mature the earlier fruits, but the effort so far exhausts available moisture that the tree would afterwards fail of growth enough to fill out fruit buds for the following year. One irrigation at that time, accompanied by a summer pruning of excessive wood growth, has a tendency to develop fruit spurs, maintain verdure and leaf action, and bring the tree to the close of the season in good condition for the next year's bearing. This application is also about 3 acre-inches of water per acre.

The above are used singly when either one or the other seems to be all that the tree requires. Where the need is apparently greater the two are given. This does not seem to be a deep indulgence in irrigation, and it is not, but it is great from the fact that it holds the secret of profit in the orchard; first, in making fine, marketable fruit; second, in laying the foundation for the same result the following year.

FALL IRRIGATION.

Fall irrigation for deciduous trees is found advisable where the rain resources of the region are very scant, so that there may be too great drying of the tissues of the tree during the long, hot autumn, and where prolonged activity of the tree does not encounter killing frosts. In some such places the too early dormancy of the tree is followed by undesirable fall bloom, which can be prevented by prolonging fall growth until a later dormancy. In regions of greater cold, and especially in the interior valleys of the northerly portions of the arid region, late irrigation must usually be carefully guarded against, because it is very necessary that the tree should become dormant early and fully harden its new wood. For the same reason, summer cultivation must stop sooner toward the North, so that a degree of dryness in the soil shall warn the tree to complete its work for the season and prepare for frosts. On the other hand, at some interior Northern points it is necessary to use late fall irrigation to guard the tree against injury by evaporation in dry winter atmosphere. It has been demonstrated that trees adequately supplied with moisture are less liable to winterkilling. These lessons of experience are akin to others previously cited—that adequate irrigation is of inestimable value and that excessive irrigation is dangerous.

Quite different is the practice with autumn and winter fruiting trees which are by their nature restricted to the semitropical regions. Fruits of the citrus family are the most conspicuous instances. They take almost a year to accomplish what the deciduous trees do in a few months. The high summer heat which ripens Northern fruits brings vigorous growth and development to the citrus fruit, but the wonderful chemistry of the ripening processes is restrained. It is reserved for the cooler months of winter. As the tree has no long dormant season, but a number of short naps at intervals, its moisture supply must be continuous and the irrigator must be ever ready to supplement the rains with irrigation as may be necessary all through the autumn months and, on occasion, even into the winter if the rains fail. Size, quality, and all the characteristics of a perfect fruit, in winter fruits as well as in summer fruits, are all conditioned upon adequate moisture, and the longer the growing season of the fruit, the more water needed, as a rule. Even the olive, which stands at the head for drought resistance, will shrink and shrivel its ripening fruit until its moisture needs are met. The amount of water required and the time of its application depend, then, upon the nature of the growth, as well as upon the nature of the soil which supports it.

FLOWING WATER VERSUS FALLING WATER.

A question which has been mooted for years and discussed with all the force of prejudice and self-interest, as well as of honest doubt, is whether the application of water by the art of irrigation is as good for the plant and the fruit as application by rainfall. The proposition naturally arrayed rainfall districts against irrigated districts, created disputes about land values and over land buyers, between land owners in this and that region. Whether irrigation was an advantage or a misfortune was hotly discussed. The question is now practically settled by demonstration to be found in the experience of thousands, that there is practically no difference between water that flows and water that falls; that there may be too much or too little of either one, and evil will result in either case. Obviously, with irrigation available there is always at first a disposition to use too much water; and to the unwise use of water are due the evils which have been charged against irrigation as such. Some of the phases of the matter are worth brief mention:

(1) The claim that nursery trees grown by irrigation were, from that mere fact, inferior was based upon experience in transplanting trees which had been unduly forced by overirrigation. Immense growth from the bud in a single season of an inch and a half in diameter and 10 feet in height tempted buyers who wanted to get as much as possible for their money. The result of setting out such trees created a strong prejudice against irrigated nursery stock. It is now clearly seen that moderate, thrifty growth is the ideal in a young tree, and if the soil does not hold rainfall enough to secure this, water enough to secure it must be applied.

(2) The claim that irrigated fruit is lacking in aroma and flavor was based upon observation of monstrous, insipid fruit which had been forced into such abnormal character by excessive irrigation. Growers who concluded therefrom that irrigated fruit was necessarily inferior denied water to their trees and gathered small, tough, unmarketable fruit, because there was not enough rainfall to enable the trees to perform their proper function. As it is now conceded that the highest quality, including the delicate aromas and flavors, can be secured only by adequate moisture, it matters not how long since it fell from the clouds nor by what route it reaches the roots of the trees.

(3) The claim that irrigated fruit could not endure shipment was based upon the bruising and collapse of fruit which was unduly inflated by overirrigation. The best fruit for shipping is the perfect fruit, and that is secured as just stated. The fact that the greater part of the fresh fruit shipped across the continent from California has been more or less irrigated, according to the needs of different localities, has settled the point beyond further controversy.

(4) The claim that canners objected to irrigated fruit was based upon the early experience with overirrigated fruit, which lacked quality and consistency. At present the canners encourage irrigation and all other arts of growing which bring the product up to the standards they insist upon.

(5) The claim that irrigated fruit is inferior for drying has the same foundation as the preceding claims, and is just as clearly based upon misapprehension. Watery fruit is obviously not fit for drying, but such fruit is the fault of the irrigator, not of irrigation. One of the plainest deductions from experience is that small, tough fruit makes unprofitable dried fruit, and that the best development of the fruit is essential to the best results from drying. Many comparative weighings have shown that the greatest yield in dried form has been secured from trees which have had water enough to produce good, large fruit. Even to bear fruit for drying, then, the tree must have moisture enough to develop size and quality. If lacking moisture, the tree serves its own purpose in developing pit and skin and reduces the pulp, in which lies the grower's profit.

It thus appears that so far as growth and quality for various uses go there is no peculiar virtue in rainfall, and there is every advantage in wise irrigation, which means using water at proper times and in proper amounts and at proper temperatures. The experience of centuries in various countries shows that irrigation water is often superior to rain water in that it carries greater quantities of plant food.[1] Pond and stream waters in humid regions are often rich in nitrates, which are the most costly and stimulating fertilizers. The surface waters of the arid region are also notably rich in potash and other valuable ingredients. No doubt in many instances irrigation water, except that which comes from wells, is worth in manurial content as much as it costs to secure it, leaving its more obvious benefits a net gain to the irrigator.

DEVELOPMENT AND UTILIZATION OF IRRIGATION WATER.

Development and utilization of irrigation water on a large scale involves engineering and financiering which can only be suggested in this connection. They constitute one of the most important economic questions of the day and are deeply involved in the progress and prosperity of the country. Either proprietary or cooperative enterprises

[1] This is fully described by Professor King in Farmers' Bulletin 46.

covering considerable acreage require the best professional guidance, and losses and disappointment have resulted from neglect to secure it. There are, however, many individual efforts in the development of water sufficient to vastly increase and improve the production of a few acres, which can be profitably undertaken, perhaps, on the basis of brief suggestions drawn from the experience of others.

DIVERSION FROM STREAMS.

The earliest irrigation efforts consisted in turning aside a part of the flow of a stream into a ditch leading to fertile land at no great distance. An obstruction in the stream sufficient to cause this diversion was often of a cheap and temporary character, which might or might not withstand the periodic freshets—it did not much matter whether it did or not. This operation is very simple and well understood, for there is no particular difference between a diversion for irrigation and one for turning the wheel of a sawmill or gristmill, except that the irrigation diversion is usually more easily and cheaply done because the needed head of water is much less. The "millrace" of the Eastern States, as the writer remembers it, would have made quite a respectable irrigation canal and have supplied a large colony of irrigated farms in the arid region. The "open ditch" cut for the drainage of an upland swale on many Eastern farms would carry enough water to irrigate a good large stretch of meadow or fruit land. Anyone who understands enough of leveling to run the line for an open drainage ditch can do the same for an irrigation ditch, and the cost of construction is the same. When there is but slight grade to the land, so that care is necessary to strike a line which will move off the drainage water with as little fall as will promote flow, the problem is exactly the same as to take out water from a point upstream and deliver it so that it will command the greatest possible area for distribution from its outfall. This elementary lesson in irrigation engineering is understood everywhere in the humid region, and yet possibly some who have only heard of irrigation as something practiced on the Great American Desert have looked upon the taking out of an irrigation ditch as a mysterious art. It has become mysterious, it is true, through the maze of water rights and wrongs in the laws, and it becomes wonderful also when one has to consider miles of construction through sand and rock and loss by seepage and evaporation and all that, but these things will probably intrude in a very mild form, if at all, in the class of small irrigation developments which belong to individual efforts in States where water is nearly as free as air. Many an idle brook can render very valuable service on a farm without losing volume enough to be noticed, or if the flow be lessened it can be reenforced by the development of more water along its upper courses.

PUMPING FROM STREAMS AND LAKES.

Where large streams are adjacent to fruit lands and diversion at a sufficiently high level is not practicable, elevation by pump to a proper point for gravity flow or direct application from the discharge pipe of the pump is being largely resorted to. On a small scale current wheels[1] and modifications of the Persian pump are employed.[2] The latter is readily operated by horsepower and is cheaply made at home with available lumber and gearing. These contrivances can be constructed and installed by the ordinary farm mechanic. On the river-bank lands in California very large steam and gasoline pumps are used both for drainage and irrigation at different seasons of the year as either is desirable. Recently capacious pumping plants installed upon barges have been used for custom pumping, delivering water to river-side orchards at a reasonable rate. Hydraulic rams are also used to a limited extent where conditions favor them.

A very interesting way for taking water for irrigation when the river is running high between levees which protect reclaimed land is the use of siphons over the crown of the levees. To cut the levee would be dangerous and flood gates are few, but water can be delivered here and there by the siphons as desired. Made of galvanized iron strong enough to resist the pressure, the air is exhausted by a pump and the water flows over. Some of the siphons are 2 feet in diameter and deliver a large stream, though smaller pipes are generally employed.

DEVELOPMENT OF UNDERFLOW.

Many streams that flow along over beds of gravel only show part of their water to the poet or fisherman who sits upon the bank. There is usually an underflow beyond all expectations. This is notably the case in the arid region, where the country is so largely made up of rock débris in the form of rock powder, sand, and gravel, through which water readily sinks and pursues its seaward course along the deeply buried bed rock. If there be a water-tight obstruction, such as a dam of concrete, placed upon this bed rock and brought up to the bed of the stream the underflow will rise and add its volume to the ordinary surface flow of the stream at that point. In this way in the arid regions large irrigation supplies have been developed in the beds of streams which in the summer consisted of dry sand and bowlders until the new water was brought to light. This has been done hundreds of times and has multiplied irrigation supplies beyond anticipation. This method lies at the foundation of some large irrigation enterprises and of some of the smallest individual affairs as well. Its feasibility depends, of course, upon whether there are water-carrying media below the bed of the stream, and that can be ascertained by digging or boring. If such be found and moving water be discovered, it is likely that the stream bed is a reser-

[1] U. S. Dept. Agr., Farmers' Bul. 46.

[2] Water Supply and Irrig. Papers, U. S. Geol. Survey, Nos. 1 and 14.

voir which needs only a bed-rock dam to deliver its water at the surface. It is a reservoir of most excellent character, because it can not lose water by evaporation nor capacity by deposit, nor can its dam be disturbed by flood or pressure.

The tunnel is another agency for developing underground water at a chosen delivery point. It has been aptly called a horizontal well. It pursues a spring to its base of supplies; it intercepts water which is moving down between impervious strata and brings it out where it will be useful. Many acres on some farms adjacent to the hills are irrigated by the flow from tunnels and the water is secured at a level which admits of its distribution by gravity on the lower lands.

Perhaps the largest aggregate development of irrigation water from underflow in the humid regions may be realized from employing tile drains as feeders for farm irrigation works. At present these drains discharge the water at once into the country drainage and the quick transit of the water to the rivers developes ruinous floods. It would be of inestimable advantage to hold part of this water to render valuable service to production later in the season when drought may come. Though the aggregate may be great as stated, the realization of it will be by means of tens of thousands of small agencies capable of being arranged by the individual farmer. He has his tiles to relieve upland swales and boggy hillsides of their surplus water. He can easily collect this water in a homemade reservoir from which it may be distributed to orchards or small fruit fields on the richer land below. In this way the farmer with no running water on his place may turn his higher land into a catchment reservoir, which will deliver its accumulations gradually, so that they may be easily controlled and rendered available at the time of the greatest need. All this presupposes the existence of farms comprising uplands and meadow, but both need not be in the same ownership. The owner of lower lands can often use his neighbor's higher farm as a catchment area by taking the outflow from his drains. Such recourse may be denied to the plains and prairie farms, but they may have other sources of supply, as will be suggested.

PUMPING FROM WELLS.

Sinking wells into water-bearing strata to secure irrigation supplies is now being resorted to as never before. New and broader conceptions of the relations of subterranean water to irrigation have recently prevailed. This follows because it may be much cheaper to raise water to adjacent towers than to catch it in a remote ravine and pipe it for miles. However this may be, irrigation undertakings have been recently established very largely upon wells and pumps or upon flowing wells, wherever they can be had. In California during the last three years there have been perhaps ten times as many pumping outfits set up for irrigation as had been employed during the whole earlier irrigation development of the State. Large irrigation companies sank groups of wells and pumped from them into their distributing ditches and flumes when, for lack of rain, their immense reservoirs went dry. Individual irrigators sank wells and bought pumping plants when the ditch water failed, and have now learned the superiority of home supply, to be drawn up just when it can be used to best advantage, and often to be had for much less than the rates of the ditch companies. Large regions which had never secured irrigation systems, and doubted, perhaps, the need of them, were forced by drought to seek water, and having found it below ground in ample quantities they will not fail in the future to use irrigation as a supplement to the rainfall. To illustrate this advance in well irrigation very comprehensive data are found in the following outline of a systematic inquiry:

In Santa Clara Valley, one of the leading fruit regions of central California, there are about 1,500 irrigating plants of all kinds in the valley proper. About 900 of them have been put in during the past three years. Many of them have centrifugal pumps run by steam. These are the larger plants, from where 15 to 40 horse-power, and in some instances more, are used, and the size of the pumps ranges from 4 to 12 inches. Most of the smaller pumps are run by gasoline, though several use crude oil, and many of them are also centrifugal. Some of these are deep-well pumps, and they are very satisfactory in raising water from a greater depth than 100 feet. From 100 to 500 feet they work admirably.

The cost of pumping differs materially with the different kinds of power, sizes of pumps, and depth of wells. Figuring from what may be a safe average of the actual cost of fuel, a No. 4 pump, centrifugal, with gasoline as power, at 70 feet depth, would cost $3 per day. This would result in 600 gallons per minute, 36,000 gallons per hour, or 360,000 gallons per day of ten hours. Such a stream of water is calculated to irrigate about 5 acres per day to a depth of a little more than 2½ inches. But these figures being of the best experiments, a better and safer estimate would probably be 4 acres per day to a depth of about 2 inches.

But, generally speaking, it is safe to say that at a cost of about $3 per acre for the water the orchards of Santa Clara County can, under the present process, be irrigated two or three times at $6 to $9 per acre per year. The average cost of plant is about $1,200.[1]

Santa Clara County is a region of rather deep wells and the cost is correspondingly high, both for the plant and for the water delivered. In many cases the cost per acre will be only a fraction of that given. But even the higher figures are below the cost warranted by the saving of a fruit crop, as the experience of individuals has shown. These figures are, however, used as a standard, because they are a deduction from broad data, and it is unwise to proceed either upon minimum cost or maximum value produced.

Over large areas of the country windmills are used as motors for irrigation pumps, and careful accounts of their efficiency are available.[2] They unquestionably serve an excellent purpose under favorable conditions up to the limits of their capacity, but irrigation for fruit growing, except in the family garden or on small areas of small fruits, is proceeding upon the basis of motors of higher efficiency. Gasoline

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[1] C. M. Wooster, of San José, California.

[2] Water Supply and Irrig. Papers, U. S. Geol. Survey, Nos. 8 and 20.

engines are being used even up to a capacity of 5,000 gallons of water per minute, but the ordinary plants are less than one-tenth of that. Crude-oil engines are also used, and steam plants using small stationary and portable engines are pressed into service, while electric motors, along long-power circuits from generators at waterfalls or other great sources of power, are being fully employed. Instances of the profitable employment of all these agencies are abundant all through the fruit-growing districts of the arid region.

STORAGE OF WATER FOR IRRIGATION.

As the diversion and development of irrigation water on a large scale can only be undertaken with ample capital and the best professional advice, so the storage of water in large volume is an undertaking which should be approached by the same route. There have been so many disappointments and such great losses from ill-advised and hasty planning and construction that the public should have learned wisdom in this direction. Even some of the smaller reservoirs have proved to be so insecure or leaky or subject to rapid filling that it is clearly seen that the storage reservoir must be first-class in all the branches of its engineering from location to construction. Still, the great storage reservoir is the sole hope of development of vast areas of the public domain, and all the lessons of experience of the last half century's irrigation engineering in California will be helps to make the new work effective.

But while the large reservoir involves these great problems, the small reservoir which will yield value a hundredfold its cost to a farm, or a small group of farms, perhaps, and be a perpetual surety of profitable production, is neither expensive nor difficult to secure. This is fortunate, because the small distributing reservoir is really the key to the satisfactory use of such small sources of water as are chiefly contemplated in this writing. To distribute water satisfactorily, which involves even spreading over a considerable area in a short time, with the best results to the land and the owner, the water must be had with a certain volume, or "head" as it is usually termed in irrigated regions. A little rill from a spring which, if left to its course, might make only a little sedgy strip across a field or a marshy spot in a corner, can be led to a small water-tight reservoir and it will accumulate until it has a volume which can be spread over a considerable area of ground and possibly increase production the first year, because of the irrigation, more than enough to pay the cost of the reservoir which collected it. This is a fact often shown in experience, and yet millions of such springs are allowed not only to waste themselves but destroy much good land unless drainage intervene and the water only be lost. Only people who have learned the value of irrigation can appreciate the value of this waste and the ease with which it can be turned to profit. Saving the pennies is a traditional method of wealth gaining; saving the drops of water might be a more apt illustration, considering how hard the pennies are to get. This matter is so important and so attainable with little more than the idle time of man and team that it seems worth while to enforce it with a little calculation: A little spring which runs a gallon a minute yields 14,400 gallons in ten days. This is water enough, if kept from leakage and evaporation, to cover half an acre of ground to a depth of 1 inch; and the same volume flowing continuously would be equal to an annual rainfall of 36½ inches for the same area. Thus a trickling stream from a spring becomes a measurable factor in production, and from this minimum flow and acreage one can easily calculate what large flows will amount to, whether they come from spring or windmill or other source. Simply collect the water into a receptacle of known capacity and note the time required to fill it, and calculations as to reservoir capacity needed and area which may be covered in the distribution are easy. Allowance must be made for evaporation from the surface of the water in the reservoir. The approximate evaporation in any region can be obtained from the nearest station of the United States Weather Bureau. Further allowance must be made for loss by seepage, which will vary with the nature of the soil in which the reservoir is constructed, and the manner of construction, which is discussed under the following heading.

An inch over the whole surface irrigated once in ten days, or 3 inches once a month, according to the depth and the receptive character of the soil, will insure against drought and increase production even in a humid climate, while in the arid region it will establish an oasis of fruits and vegetables in succession through the dry season. In the midst of such surroundings the country home becomes attractive and beautiful where otherwise it would be bleak and desolate. The improved home is the unit in the computation of irrigation advantages.

THE SMALL RESERVOIR.

Obviously the small receiving and distributing reservoir should be above the highest point of the land to be irrigated and below the source of the water, except with pumping outfits. It should also be as near as possible to the land to be irrigated, as increased distance would increase both the cost of conveying the water to the land and the loss of water from seepage and evaporation. The first thought in small affairs in hilly regions is to imitate large undertakings and dam the natural channel and back the water in the small ravine whence the stream flows. This is often wise, perhaps, but it is also often difficult to escape loss by seepage and to get sufficient capacity without too high a dam, and there is such great danger of washouts by excess of storm water that a reservoir out of the course of the stream, to which water may be conducted, is better. Excellent suggestions on the construction of the small reservoir, with cross-section drawings, are given in Farmers' Bulletin No. 46. In a coarse soil thorough puddling of bottom and sides with clay loam, or a mixture of clay with the local soil, will make the reservoir hold water, but a lining of cement or asphaltum will be better where there is not frost enough to break up such materials. In

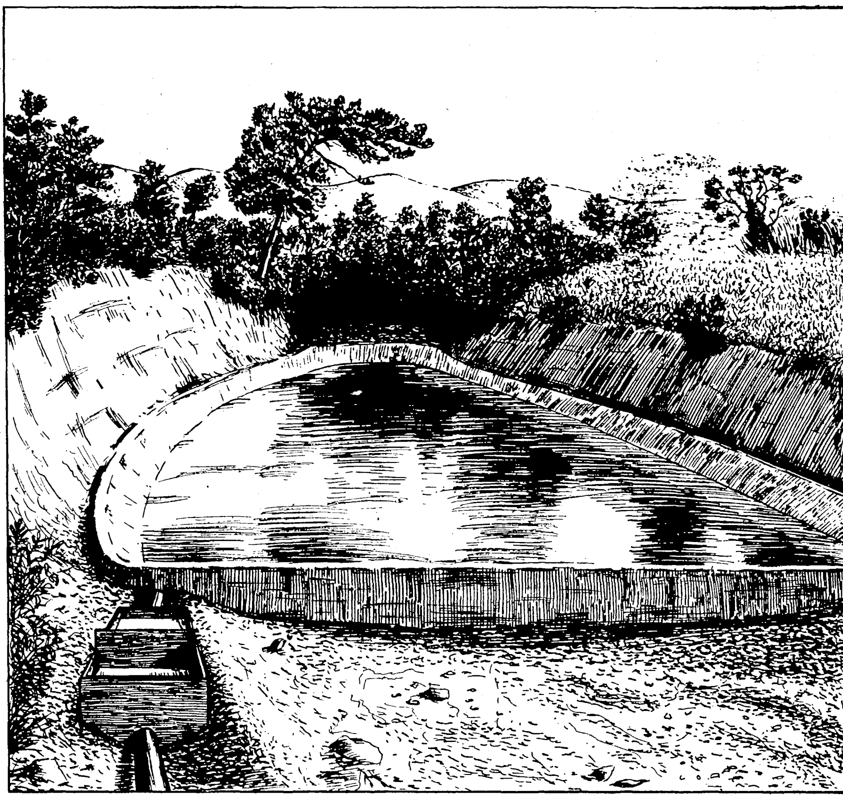

FIG. 1.—Cement reservoir for collection of water from a pumping plant, and its measuring box.

California well-constructed small reservoirs, with concrete bottom and walls thoroughly plastered with pure cement, are frequent and are very satisfactory, though expensive. (Figs. 1 and 2.) Probably, however, a

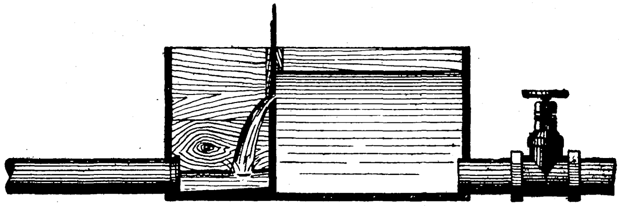

FIG. 2.—Measuring box used in connection with distribution from small reservoir.

small reservoir which is most generally attainable and is easily home-made is a tank of dirt. The following is a condensed description of such a reservoir, by Theodore Sternberg, of Kansas:

A dirt bank and bottom is the best and least expensive of all substances from which to construct the pond. Surface soil is the best. Clay may do well for bottoms, but for banks it is useless, because, when the inner bank is exposed, clay at once cracks, but surface soil does not.

The very best shape for building easily and using horses and scraper is an oval, or at least rounded corners, the curve such that a team with scraper can easily be driven all around on the bank. Having marked out the extreme outside limits of the pond, if it be in sod, carefully remove the sod and pile it up out of the way, to be used later on. Then thoroughly plow the whole space where the banks are to rest, as well as the pond part; then, with cultivator, harrow, and garden rake, work down as fine as possible the dirt upon which the bank is to rest. Keep the team going over and over the bank foundation until it is fine and packed as firm as possible. If the banks are built upon the natural surface there is always a crack; the ground must all be worked for the banks, from the bottom of the pond up to the top.

The foundation of the banks being made, then, with team and scraper, move the plowed dirt from the bottom of the pond and dump it on the bank; start the bank 12 feet wide; for 4-foot banks 12 feet at the bottom is not too wide, and the top at the finish will be about 3 feet wide. As the dirt is dumped, spread each scraper load evenly; break up every lump, work it fine, and fill the tracks of the horses. This settles and packs the banks even and hard. The secret of good banks is the fining the ground and keeping it level as the banks rise, so that the whole is uniformly packed solid. The horses and heavy scraper do this all but the edges; pack the edges by walking back and forth, as in making a garden walk. The dirt from the first plowing being all removed from the pond and placed evenly all around on the banks, plow deeply the bottom, then, with harrow and cultivator, make this dirt as fine as possible to puddle the bottom. This bottom dirt being all fined to a depth of 8 inches, weigh down the harrow, put on your rubber boots, and turn on water; harrow, harrow, until this plowed ground is a thin paste. The bottom is made, and if the soil is loam the chances are that it will hold water.

Put in the sluice box or iron pipe through which the water is to be drawn, ramming well around it clay and chopped straw, so that not a drop of water can follow along the outside of it.

It takes time to make a pond. Even after this work has been done, time is required to settle and solidify bottom and banks. Therefore it is better to build the pond in the fall, so that it will be ready for use the following season. One of the very best ways to puddle the bottom of a pond is to keep the bottom damp and feed cattle in it for a couple of months. The balance of the banks may be finished at leisure. Use any kind of dirt which is most convenient for completing the banks; still surface dirt is the best for the pond and best to start grass on. When the banks are as high as the horses can readily walk on, then take the sod, if you removed any, or sod or stone, and build on the outside a wall 2½ feet high, fill in with dirt, and finish off the bank with the shovel. Be sure and not fill the pond up rapidly with water; fill it up 6 inches higher every day or two and draw it off; this is to settle and firm the banks. Until grass or plants can grow on the inner bank, to prevent washing down, have a lot of loose boards floating in the pond, and see to it that they are in position to break the waves when the wind blows.

Through the bank place a galvanized sheet-iron pipe to carry off the water when it reaches the height desired; put a joint in it at the outer end, to let the water down without being blown back against the bank, thus washing it away.

These definite details are given to show how easily small storage of water from any source of supply can be secured. The pond above described is about 50 by 55 feet and 4½ feet deep. Similar construction can be carried for a considerably greater area with safety and satisfaction. This reservoir is nearly all above the surface, because the water was to be used close by on land of about the same level. Where the reservoir site is elevated, of course more excavation and less bank building can be employed, but the careful puddling is usually necessary to escape danger of leaking, unless a lining of asphaltum or cement is preferred.

TAKING THE WATER TO THE LAND.

Conveyance of water from the reservoir to the land to be irrigated is accomplished in various ways. The cheapest in point of first outlay, but in some respects the most wasteful, is the open ditch. If the distance be considerable, it is wasteful of water by seepage, wasteful of land, troublesome and unsightly in the rank growth of weeds, which, unless carefully cleaned away, ripen much seed for the water to spread over the irrigated land. Irrigation water vies with the wind as a weed distributor. Then, too, ditch conveyance depends upon the grade of the land to be traversed. If it is possible, loss of water can be reduced by paving the ditch with stones laid in clay, or it may be cemented, but still it lies in the way of cultivation and will vex the owner until he summons courage and capital enough to put in a line of "pump logs," or round tile, or cement pipe, or steel pipe sunk below the reach of the plow. Which will be best in land which freezes deeply local experience in water piping will decide. In the irrigated region this problem seldom intrudes, and all sorts of pipes are satisfactorily used. Riveted steel pipe, with size adjusted to the area to be irrigated, and with valves at the reservoir and at the discharge point, is the best arrangement. With such a pipe water can be carried over uneven ground by the shortest route and it will save a vast amount of loss and trouble. Of course all this is escaped if the reservoir be situated at the highest point of the immediate tract which is to be irrigated, but there may be many reasons for having it at a distance.

DISTRIBUTION OF IRRIGATION WATER.

The distribution of water on land to be irrigated involves a certain amount of engineering. The laying out of a system should be done by a competent surveyor who understands the regulation of the fall of the ditches according to the soil to be traversed, the volume and character of the water to be carried, etc., and the levels along which it can reach the different ridges by which it can be handled on the different irrigation faces, if the surface be somewhat uneven or rolling. It will not pay to guess at any of this work. It should be well done at first. There have been many instances of loss through wrongly located ditches. Some of the earlier systems somewhat hastily laid out have left so much land above the ditches, by giving the water so much more fall than necessary, that practically a new system has been laid out above the old one by carrying the water higher up, as it should have been done at first. All such enterprises on considerable scale call for professional advice from irrigation engineers. Of course the same principles hold in small distributions, but one need not greatly err in the application of them to small pieces of ground if he will take a little pains; consequently some suggestions will be offered.

There is little ground so nearly level that water will not flow over it in some direction, but the grade may change so that distribution should be arranged from different secondary sources, or if distribution be from a slight ridge water may be taken on both sides of the same source for the different slopes or faces which are to be irrigated. The eye can not always be trusted to determine these directions. The simplest sort of a surveyor's level can be used by a layman for this work, but it is also possible to do it with homemade leveling devices which should be on every farm for location of drains, irrigation ditches, private hillside roads, grading land, or anything of that sort. If these are not available the beginner can return to first principles and take along a little stream of water with a hoe, and note the line on which it moves without cutting or showing a disposition to back up.

Ditches, flumes, and pipes.—When the supply lines of the land are located the means of conveyance are next to be decided upon. The ditch is the cheapest and at the same time the most troublesome and wasteful of both land and water, as has been heretofore shown. Though the ditch is largely used in handling large heads of water for the quick covering of large areas by flooding, for the handling of smaller heads through longer runs for other methods of application the ditch is generally superseded by flumes or by pipes with hydrants, or by open pipes or troughs.

Flumes are sometimes V-shaped but are usually rectangular and consist of a bottom and two sides, as this carries the water in good form for frequent diversion and openings are more readily contrived. Some have gone to considerable expense to construct these flumes of cement, or flat stones cemented together, because of the imperishability of the materials. Some of these are very neat, but it is very doubtful whether, on the ground of durability, they are worth the cost. They are easily cracked and chipped in working the adjacent ground; it is much more difficult to arrange openings and to close them, and in regions of hard freezing they would probably prove anything but desirable. The decision of irrigators, generally, is that a well-made board flume is good enough and by far the most available and most easily repaired, but it is very important that the flume should be made of sound lumber of whatever kind is least liable to crack or warp in the locality and will have the longest durability under alternating wet and dry conditions. The construction of the flume, the grade, and the character of the openings will vary according to the method which is to be used in the application of the water. Constant attention should be paid to keeping the flumes in good repair and water tight, because a leaky flume is not only wasteful of water but is a menace to the thrift of adjacent trees by excessive moisture. Losses have occurred by carelessness in this matter.

Distribution through buried pipes and hydrants is satisfactory for flooding, or for use with closed hose and sprinkling attachments, but sprinkling is practically unknown in the irrigated region except for lawns. Even for small fruits and vegetables in garden practice surface distribution is found to be much superior to any imitation rainfall, in economy of water, depth of penetration, subsequent stirring of the surface to check evaporation, and the condition of the fruit itself. Dry air, dry surface soil, and ample moisture at the root are found by long experience to be ideal conditions for perfect foliage and fruit.

Distribution from hydrants with large open hose, or open galvanized pipe, to take the water to prepared basins around the trees, or to connect hydrants with small lateral ditches, etc., may often be economical of water and valuable in delivery at certain desired points, but little piping is actually used in the irrigated region except to convey water to points from which it is distributed by flumes, or small ditches. There are conditions, no doubt, in which a freer investment in pipe than is now made would be profitable in the end.

PREPARING LAND FOR IRRIGATION.

Having thus brought the water to the distributing points on the land to be irrigated, it is desirable to suggest preparation which will facilitate the ease and evenness of application to the whole of the land. This is done by grading—not by leveling nor by securing any given slope, but merely to correct elevations and depressions upon each slope or face over which any water is to be run. If this is not done there will be sags or swales in which too much water will collect and knolls or humps which will get only what they can secure by capillary rise, and not enough to bring out their proper production. Such work as this can be done quite boldly in the arid region, because the soils are usually deep and of uniform fertility to considerable depth. To plow and scrape off knolls into sags is a safe proceeding as a rule, though in exceptional cases it would uncover areas of infertile subsoil. In the humid regions, this can not, of course, be so widely undertaken, because the soils are more shallow and the subsoils more refractory and infertile, but so far as feasible the land should be graded. For a small irrigated area which is naturally expected to yield high value, it may be profitable to haul good soil in to help bring depressions up to grade, even if the knolls are left to do what they can without water.

Drainage of irrigated land seemed to be a foolish and wasteful conflict of policies when irrigation began in the West, but later experience has shown that unless the soil is very deep and loose and the irrigation wisely applied there is considerable danger of excess of soil water, which is ruinous. Even deep, loose soils may be practically submerged by seepage from leaky ditches and excessive irrigation combined, for there are large areas in California where before irrigation was introduced it was necessary to dig over 50 feet for well water, but after ten years of irrigation the ground water rose within a few feet of the surface and made ponds and marshes in the low places. This rise of the ground water also brought up corrosive alkaline matters which work havoc beyond simple water injury. It is quite necessary, then, in many places to arrange drainage for irrigated lands, and especially where summer irrigation may be supplemented by copious rainfall. Lands which need drainage to dispose of surplus rainfall may doubly need it when irrigation is supplied.

Preparation of land for irrigation should also include deep tillage and subsoiling. This is also desirable upon other accounts as well, but with irrigation it is essential that every cultural effort should be made to promote deep penetration of the water and deep rooting of the plants.

METHODS OF APPLYING IRRIGATION WATER.

Methods of irrigation must vary according to the amount of water available, the soil, the lay of the land, the character of the crop, and there can be no best method under all circumstances. With the experience of half a century in California there have come to be a few methods generally recognized to be best, each for the conditions which govern its preference. As the writer is most familiar with these methods they will naturally be chosen for discussion, in the hope that information regarding them will at least be suggestive to those who may be contemplating work along irrigation lines in other parts of the country. Points of value in a method must include the following:

(1) Distribution of moisture evenly throughout the soil mass to as great a depth as possible, providing it does not sink beyond the reach of the plant by root-extension nor beyond recovery by capillary rise.

(2) Economy of labor both in aggregate time and in the feasibility of operating without employment of extra hands.

(3) Economy of water in the prevention of waste by overflow or evaporation or by rapid percolation, and in placing the water where it will do the most good.

(4) Leaving the land in the best condition for attaining with least labor a state of tilth which conserves moisture and at the same time favors thrift in the plant.

Whichever method most nearly attains these ends in a certain soil and situation is the best for that particular case. But no method attains them all under all conditions, and one has to judge which consideration can best be disregarded, as of the least importance, to secure other greater benefits.

PERMANENT DITCHES.

Permanent ditches are an old means of applying irrigation water. They are led out from the main ditch wherever the water will follow the hoe at about the right speed for lateral seepage in sufficient amount, and planting is done alongside about as far as the influence of the water can be counted on. The chief claim of the method is economy of labor, and that was sufficient to sway the minds of its inventors in favor of anything. It gives a very uneven distribution of water, it wastes both land and water, and it does not favor soil-stirring and plant thrift. It has no standing at the present time except perhaps as a makeshift to grow a little stuff in a corner for home use.

FLOODING.

By flooding is meant surface flow with very little restraint or guidance. It is a very rapid way to get a good deal of water over the land, and sometimes rapidity is a ruling factor when one has only a short run of a large stream. It is cheap but proportionally disagreeable, because the irrigator has to work in the water and use all his strength and speed to help the water reach all points—which however it never does in equal volume. At best the surface is partly well soaked, partly dry places, and partly mud holes, and, when cultivation follows, the plow turns up dust and mud and good, moist soil in varying proportions. For grain or forage crops flooding may in some cases be a defensible method, but the check system is vastly better even if somewhat more costly. Flooding has cheapness and speed for its chief claims, and it sacrifices all the other points. It usually requires several hands—more or less, according to the head of water which is being handled.

Flooding the orchard is sometimes improved by turning a furrow on each side of the space between the rows and then admitting the water to one row-space after another. With this slight leveeing more even distribution is secured, for all the water has to flow in a thin sheet over the ground between the furrows and has a better chance to reach all points of the surface, and where the slope is very slight it will work fairly well. The furrows protect the base of the tree from contact with the water, which is a good thing. Where orchard land is kept under a cover crop which it is not desirable to disturb this method of irrigation may suit the conditions very well, unless the land is properly checked before the crop is put in, and if this is done it is not called flooding the land but flooding the checks, which will be described later.

Flooding in general is obviously adapted to land which will take water rapidly, because the run is short, and a short run on a close soil sends the volume of water across the lower edge of the field before much penetration has been secured. Flooding, therefore, is generally deceptive, and the land gets much less water than it seems to. It is directly opposed to the furrow system, which will be described presently. If that is attempted on land which takes water too readily it will get much more than it seems to get, because there will be no satisfactory lateral seepage, but too brisk vertical percolation, and water can not be carried far enough. A small stream will run directly to the lower strata and out of reach of the plant if the soil is deep and rests, as is often the case, on coarse sand or gravel. For such a condition of affairs the check system is better than flooding, as will be seen.

Water for flooding is diverted wherever desired from the head ditch of the area which is being irrigated. This is commonly done with a cut in the side of the ditch, using a portable cloth or iron dam to throw the water out of the cut. These contrivances are a great improvement over the old method of shoveling dirt into the ditch. Some make a series of wooden gates in the ditch which can be slid up to let out the water at intervals. Cement ditches and buried pipes with hydrants are also used for flooding. The capacity must depend upon the extent of the area to be flooded. Wooden flumes are also used, and they are very desirable because of ease of diversion, and with a good flume the head of water can be handled with fewer men.

CHECKS.

A modification and, in most respects, a great improvement of irrigation by flooding consists in the use of what are called checks. It is really flooding by the use of levees which check the movement of the water and restrict it to definite areas, thus giving the assurance that the water shall remain on this area until it sinks out of sight. It has certain manifest advantages: (1) It makes it possible to know that a certain amount of water has actually been applied, because it is easy to see the depth of water which has stood in the inclosure. (2) It enables the irrigator to quickly spread a considerable depth of water over the surface, and thus bring even moisture to soil so leachy that a small application would disappear vertically without lateral seepage. (3) It facilitates the use of a large run of water in a short time. (4) It gives satisfactory irrigation where other methods fail.

The development of the present systematic check system from its antecedent flooding system was gradual. It began with imperfectly formed levees made with the plow at irregular intervals, and subject to breaking away on the low side, because the water collected there, and left the high side out of the water and consequently less thoroughly soaked. To meet this and replace crude methods of handling water in filling checks, improvements have been made in the system until at the present time the levees are quickly, evenly, and strongly made by the use of special tools and methods, and the handling of water is so successful that the work can be most rapidly done with little chance of break or runaway water. It has become, in fact, a model of even distribution of water. It does, however, require the shifting of considerable earth, which has afterwards to be worked back to its place before cultivation of the whole surface can be undertaken, and as the ground has been so thoroughly surface-soaked it must be worked immediately upon the arrival of proper condition, to escape baking and a cloddy surface which is difficult to pulverize. Fortunately, however, the disposition to run together and bake renders the soil better adapted to the use of the small-furrow system which is the ruling method for such soils. All forms of flooding or checking of cultivated land succeed best on a light, coarse soil which takes water most easily and suffers least from water standing for a time upon its surface.

Checks along contour lines are little used in fruit growing at the present day; they are specially adapted to the irrigation of alfalfa or grain fields. Where the grade is slight and uniform and the contour lines are nearly parallel some fruit lands are handled in that way.

The prevailing method of checking orchards is to disregard contour lines because the slight departures from the level can be easily met by a little increase in the height of the levee on the low sides. Levees are, then, usually made between the rows so that each tree stands in its own inclosure, though in some cases the checks are made larger. The size of the check obviously is governed by the slope of the ground. The success of the check system depends very much upon being thoroughly ready before the water is turned into the head ditch or flume. The proper thing to do is to plan the operation out well from start to finish and have the ground all ready. If that is done the amount of water each man will handle is very great.

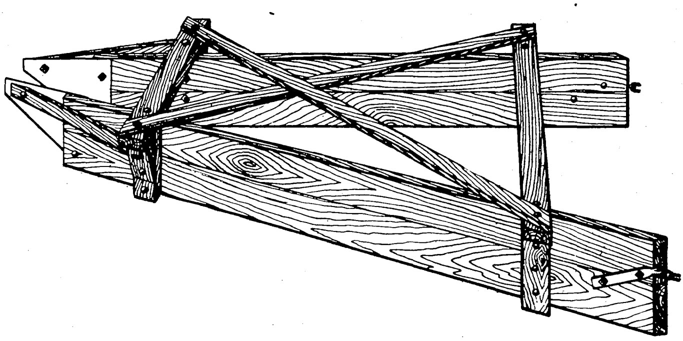

FIG. 3.—"Ridger" for levee making in the check system of irrigating trees and vines.

The first step after deciding how the water shall be run is to loosen the surface, both for absorption of water and to secure plenty of loose soil to make the check levees or ridges. The plow is often used. More recently the disk harrow, cutting a good depth, has become popular. Some work the whole surface of the ground, others only plow a few furrows or run the disks about where the ridges are to be made. If the soil is quite light and it has been kept well cultivated the latter method will do very well and save time if the checks are to be of good size. There is what is called "single checking," in which one series of checks covers the ground from the center of the interspace of one row of trees to the center of another; "double checking" is that in which two series occupy the same space, one series inclosing the trees, another being wholly in the interspace. Single or double checking depends upon the slope, the more rapid the slope the smaller and more numerous the checks needed to hold the water evenly upon the whole surface.

The ridges or levees are made very perfectly and quickly with three implements for horse use; the "ridger," the "jump scrape," and the "crowder," which can be readily described. The "ridger" (fig. 3) is a sled with rather deep, solid runners made either of plank or sheet steel. These runners are set nearer together behind than in front, so that when moving forward the quantity of loose dirt taken in front must rise to escape through the narrow opening behind. The result is that when the man jumps on the sled and starts the team the runners sink in the loose dirt, and as it goes forward this dirt is left in a ridge in the wake of the sled. As the platform of the sled is rather high, because of the deep runners, it can be run again over the same ground and raise the dirt higher. In this way the chief work of the ridging is done by working from row to row of trees, back and forth, usually making first all the ridges which are parallel to the head ditch or at right angles to the flow of the water. When these are all made the ridger is started at one side of the land and the ridges at right angles to those first made are put in and the land is marked off in squares like a checkerboard.

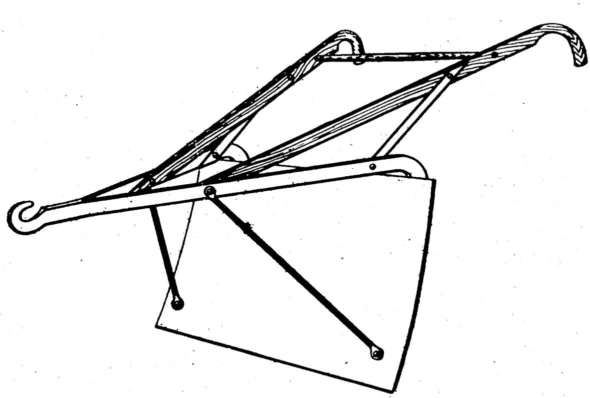

FIG. 4.—"Jump scrape" used to complete levees made by the "ridger" for the check system.

The checks are, however, not yet ready to hold water. Where the ridger has crossed the first ridges in making the cross ridges it has broken down the first, and the corners are therefore imperfect. Repairing of these corners was at first done by hand shoveling, but a labor-saving device called the "jump scrape" (fig. 4) is now widely used. It consists of a slightly curved plate of steel fastened to a standard with beam and handles like a light plow. With a light horse a man starts down through the checks close to the last made ridge, and as each corner is approached he sinks the handles so that the shovel plate takes some dirt, and at the right point he throws this dirt into the corner without stopping and proceeds, doing the same thing in each imperfect corner. After this very little is needed to make the checks all water-tight.

This covers the whole field with checks, or rather with square areas inclosed with checks or check levees. To handle water in this arrangement it must be turned into the highest check nearest to the source of supply, and when that is filled allow it to spill over into the next lower and so on, or else the water must be carried in a detachable pipe over all the checks to the lowest one (fig. 5). Fill that, take off a length of pipe, fill another check, and so on until the top check is reached, the pipe being reconnected meantime over the next series of checks. This pipe method, using galvanized iron pipe with slipjoints, is very satisfactory where the grade is rather sharp and double checks are needed, and where allowing the water to run from check to check would be almost to invite a break away, or running the water down in a ditch outside of the checks would be likely to produce cutting and soil shifting.

Where, however, the grade is gradual, so that water even in a large stream can be safely let down in a ditch, the arrangements for filling the checks from a common source and not from each other is easily

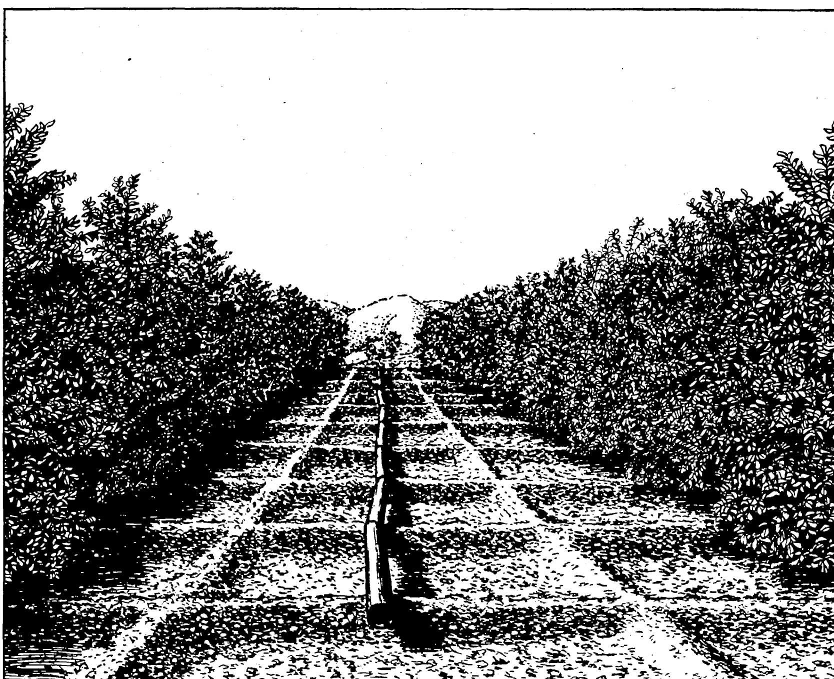

FIG. 5.—System of double checking and filling checks with detachable pipes.

made. Midway between the rows of trees the ridger is run twice on parallel lines a little apart. This makes two ridges near together which are easily made into a ditch by the use of the "crowder." (Fig. 6.) This is a V-shaped implement made of plank or iron, hitched to the horse by the apex, with handles from a crossbar, and usually having one long arm and one short one. It is merely a small, light form of the V-scraper, which crowds the loose dirt between the ridges to each side, thus clearing out and defining a ditch. The head of water for filling the checks is turned into this ditch, and as it reaches the two checks at the bottom it is let into one or both of them by cuts in the levee, and when these are filled it is diverted into the checks just above, and so on until all are filled. Sometimes the highest check on one side of the ditch is opened, then the next on the same side, and so on to the bottom. Then returning, the checks on the opposite side are opened one after another from the bottom up so that when the last is filled the irrigator is at the highest point ready to send the water along the head ditch to the next series of checks.

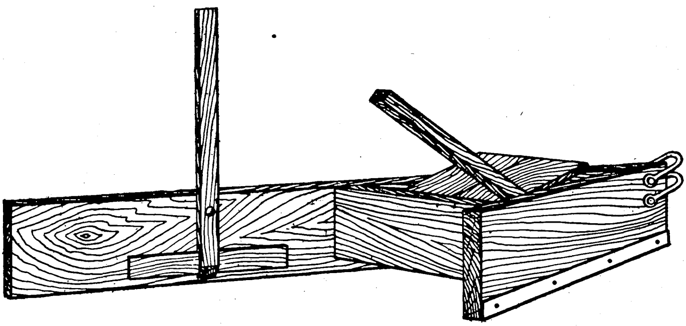

FIG. 6.—"Crowder" used in the preparation for distribution of water in the check system.

This is an outline of the work, enough, perhaps, to start a person of some ingenuity on the pathway of experience where he will learn many little and important things in the handling of water, treatment of levees, etc., all of which help to handle a stream of water without disaster but which can hardly be taught by descriptive words.

BASIN SYSTEM.

The system which has just been described, and which aims to apply water to the whole surface of the ground, is sometimes called a basin system because the water is held in small inclosures; but the writer is of the opinion that the term basin should be restricted to inclosures which do not aim at covering the whole surface, but only a small area immediately surrounding the tree. What has been called the check system is clearly a more rational and perfect method of flooding. The term "basin" will be used to signify a method which was apparently employed at first to escape the flooding system and to apply the water where it was thought to do most good. If this surmise is true the system is founded upon a misconception which has prevailed also in the practice of fertilization, that the tree derived its chief benefit from the soil immediately surrounding and beneath its bole, and that distant applications were likely to be wasted. Years ago it was held that the lateral root extension of a tree was equal to the spread of its branches, but recent investigations have shown that under favorable soil conditions the root extension is vastly greater. It is not reasonable then to restrict water or other plant food to the region chiefly occupied with the stay roots and not the feeding roots of the tree. Another error of knowledge and judgment as to the movement of water in soils was also involved in the early recourse to the basin system, and that was that the water would remain in this region which was supposed to be of most service in the growth of the tree. No adequate knowledge existed as to the thirst of the encompassing dry soil and the movement of water by lateral seepage, It is true that one of the misconceptions or errors offsets the other to a certain extent and that the water did move toward regions away from the trunk and thus minister to the outer root extensions to a certain degree, but the mass thus moistened was in such small ratio to the dry mass surrounding it that the tree was inadequately served and was continually restricted in its growth by the heat, dryness, and impenetrability of the surrounding mass, and continually losing thrift by the extension of rootlets into a region of alternating drought and moisture. The teachings of experience and observation were, long ago, in support of application of water to the whole soil mass, except in very young trees, but even with these the moisture should considerably outreach the root growth until the whole is moistened. Even where the basin system is used, for reasons which will be stated later, it is still a frequent observation that basined trees do not do so well and that they show distress sooner than those under systems which secure more complete water distribution.

The basin system may be conceded these possibilities: (1) Trees may be grown on hillsides too steep for other means of irrigation unless the hillside be previously terraced; (2) the basins afford an opportunity to use a very small stream of water by allowing it to run for a long time in each basin, thus making a miniature reservoir at the base of each tree; (3) for young trees a small amount of water may sustain growth, while with other methods the same amount of water would be almost wholly lost by evaporation or percolation, or both; (4) the expense of wider application of water and the necessary after cultivation is obviated. Against these it may be urged that, up to a certain degree of slope, double checking will secure better saturation; that experience has shown it to be dangerous to the planter to grow many young trees on the expectation of greater water supplies to meet their later needs, unless he is fortunate enough to sell out to a tenderfoot before these needs arrive; that whatever outlay may be obviated by having the larger part of the orchard area unstirred is a heavy discount upon the future growth and productiveness of the trees, and that basining without cultivation brings the soil into a dense unaerated condition fatal to plant life as far as the water reaches, which subsequent cultivation rarely brings again into condition favoring growth. Basining differs from flooding and checking in this, that it counts on shaping the water receptacles not oftener than once a year, and too generally looks upon them as permanent structures. Still, it must be admitted that there are conditions of soil, water supply, and topography which give the basins standing as the best system available under the circumstances.

In planting on hillsides, terracing is the foundation of the basin system. Terraces are plowed and scraped out until they have width enough to accommodate a line of basins and a ditch at the foot of each bank to supply them. The terraces are given a little fall, alternating in direction, so that the water, starting from the ridge above, is dropped through a box, or otherwise let down, from the low end of one terrace to the high end of the next, and so on until the stream reaches the bottom of the slope. As a basin is reached it is filled and closed and the water sent along to the next and so on. As these basins are usually small and shallow they are filled two or three times in succession at each irrigation.

Terracing in an arid region is attended with objections other than the cost. The banks are bare through the dry season, except as they may be tenanted by unhandsome drought-proof weeds, and are very different in appearance from the grass-covered slopes of the humid region. Nothing can be grown upon them except at too great cost of labor and water. Then, too, the area of hard surface occasions a great loss of water by evaporation, so that even irrigated trees may be stunted by drought. The soil of the banks, unrestrained by turf, is often cut and washed badly by heavy rains, and then fills the ditch and basin below and occasions considerable repairs. Wherever water can be handled in contour ditches or furrows, terracing should seldom be undertaken for commercial purposes.

With slopes which do not require terracing, basins on the steeper parts are largely made by hand labor, after plowing to loosen the whole surface, and the operation consists in moving the earth from the upper side of the tree, so as to form a circular levee on the lower side, until the tree stands in a level, roundish pan as large as can be made without too much excavation and filling. As the slope becomes less the basins enlarge and reach a diameter, finally, where the sides can be made by turning a small horse or mule around the tree with a plow, the rim being further raised and shaped by hand so as to hold 3 inches or more of water without danger of breaking away.

The basins are filled with a small stream by ditch or hose or pipe line, according to the ground and notion of the irrigator. They are filled at such intervals as the water supply admits or the growth seems to need. The basin bottom is rarely disturbed. The cracking soil is finally given another dose of water to close up its wounds; meantime the frequent surface soaking puddles the soil and the condition unfavorable to growth arrives sooner or later, according to the disposition of the soil to run together by water settling. Drying and cracking is lessened by filling the basin with manure or rotten straw or other light rubbish, or by a layer of coarse sand on the bottom. As the tree grows the foliage shades the basin and thus reduces evaporation.

LARGE-FURROW SYSTEM.

Next in order, perhaps, to the systems which involve levee construction should come the more or less permanent waterways near the trees, which may be considered one phase of a furrow system. (Fig. 7.) In one form it is a very old method, viz, taking out water wherever it would follow a furrow at the right speed and planting adjacent ground, relying upon the seepage from the ditch thus marked out. This has been discussed already. A method which perhaps belongs to the same class, and yet is as marked an improvement upon its prototype as the check system is upon flooding, is the large-furrow irrigation. It has two main divisions, the contour ditch on hillsides and the mid-row ditch on the level. They both act by seepage, as did the old permanent ditch, but they differ from it in being frequently broken up by cultivation, which removes the chief objectionable feature of the old ditch.

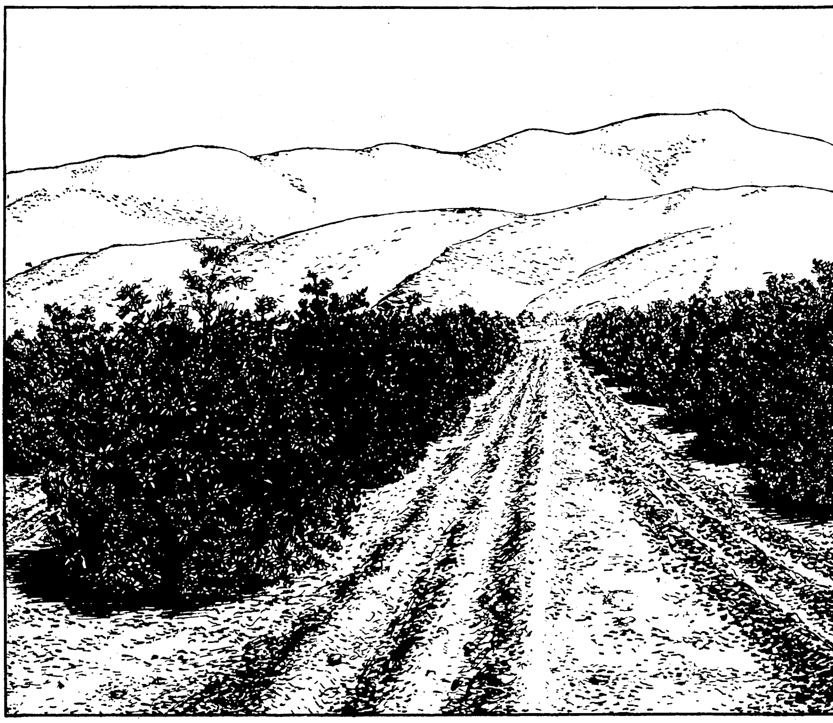

FIG. 7.—Irrigation of young orange trees by the furrow system.

On hillsides the furrows are sometimes allowed to remain during the rainy season, because they offer a convenient way to carry down storm water and prevent cutting, but they are thoroughly obliterated by the spring plowing and cultivation, and reopened when irrigation must begin, about two months later. The new furrows will probably not occupy the same ground as the old, for the line may start above at a different point, and in the rough leveling, which is done partly by the eye and partly with the surveyor's level or the triangle, there will be considerable variation from the previous season's locating. The locating is approximately on contour lines, but with such fall therefrom as will carry the water without too much speed and facilitate turning at the boundaries of the area being irrigated to deliver the water into a lower furrow which recrosses the irrigation surface. Thus, the general plan is an irregular zigzag by which the water passes from the supply at the top of the slope to the outflow at the bottom, running slowly enough to saturate all the soil to the bed rock, which is usually not far below, and which assists in the lateral distribution by the underflow along its surface. Sometimes the water is let down by a zigzag on each side of the irrigation face (irrigated area) and furrows connect one zigzag with the other, the outflow from a higher area being caught by a zigzag on a lower face and thus distribution is accomplished over hillsides with several differing slopes.

The efficacy of this single furrow or ditch is due to the fact that the bed rock prevents the escape of the water downward and the slope of the rock promotes lateral distribution. In some cases, also, the bed rock consists of plates standing on edge, between which excess of water sinks and the roots follow it. Where the rock is a flat plate at small incline there is sometimes injury from accumulation and retention of water, and drainage is necessary, while a comparatively short time thereafter irrigation is again necessary, because the shallow layer of soil can not long hold water against capillarity and evaporation, even though the surface cultivation may be good. The furrows for this style of hillside irrigation are usually put in with a double-moldboard plow, following a line of stakes previously located. On regular slopes the trees could be planted approximately on contour lines to facilitate this annual furrowing, but for the purpose of having the trees equidistant, to evenly divide the ground, and facilitate cultivation, the planting is generally done in equilateral triangles. When the furrow is put in for irrigation it may follow a line of trees for a time and then shoot across the row, one way or another, to follow the grade desired for the water. It does not matter much to the tree where the ditch runs, for the whole ground is to be saturated in the way described above.

The point of greatest difficulty in the use of this system is to secure a good turn for the water at the end of the grade. The turn is often quite sharp and the water is liable to cut. This is sometimes prevented by spreading pieces of old sacking over the dirt and sometimes a bunch of swale hay or other fibrous material bedded in the turn holds the soil fast. When the waterways are thus well fixed, after the rains are over and the starting of weeds is very scant, the orchard may be left without further cultivation for the balance of the season, water being applied to the ditches once in two or three weeks, according to the ascertained needs of the trees on the particular location and soil involved.

Large furrows on level lands are chiefly used where only a few applications are necessary and the trees are of sufficient age to occupy all the ground. To interfere then as little with the cultivated surface as possible deep ditches are plowed out midway between the rows and a good deal of water is turned in to fill all these ditches. As the water sinks away they are refilled to whatever amount the trees are thought to need, either for enlarging the fruit or for continuing the late summer growth. This method of applying water is chiefly used for deciduous trees wherever a limited amount of irrigation is required to supplement rainfall and not where systematic irrigation is the chief dependence. For lands which take water quickly this method is believed to foster deep rooting and for old trees it seems to serve an excellent purpose. It requires a considerable volume of water, such as can be had by pumping from rivers upon the orchards near the banks or from capacious wells elsewhere. It requires vastly less work than checking, both in preparation of the ground and in subsequent cultivation.

The large furrow method prevails with small fruits, and where the ground is level is used for certain distances with outward and return flow in alternate rows, the furrows being deepened enough at opposite ends to allow of a slow movement of the water during which seepage saturates the slight ridges between the furrows, upon which the small fruits are set. If this is not admissible the furrows are each given water from the flume or head ditch at one end until sufficient saturation has been reached.

SMALL-FURROW SYSTEM.

This is the most popular of all systems in California, and would be almost universal if it worked well in all soils (which it does not). It requires land in which vertical percolation is not excessive and lateral movement is adequate. Its unit is a small rill of water running for a long time, filling the ground, which, while it becomes gradually saturated, still allows the small surplus to continually proceed. The irrigation is accomplished by multiplying these rills, each doing its own work, with the result that as they all reach the bottom of the grade the whole area is deeply and thoroughly soaked. If properly done no water has flowed over the surface and it is possible also to so regulate the water that very little flows away at the lower end. This result is impossible on land that swallows up a small stream so that it might run for days and never gain more than a few feet of distance. It is also impossible upon a grade over which water, unchecked, could flow without penetration. Where a small stream of about a gallon a minute will run so slowly that, always losing water and yet never being itself lost, it will follow a furrow something like 40 rods in about twenty-four hours, the soil and the grade are both suited for this method of irrigation. Of course the size of the stream must be adjusted to the soil and the slope, but the general measure given contains a rough indication of fitness.

The advantages of the small furrow system of irrigation for land which it is intended to keep with a bare surface frequently stirred, will include the following: (1) It thoroughly soaks the ground and accomplishes even distribution without saturating the surface. By the water drawn up from the little stream in the bottom of the furrow the surface soil is fully moistened, but does not run together as it would with water standing upon it; (2) the displacement of the soil is reduced to a minimum, consequently the labor is also thus reduced, and the cost is less than of any other method which distributes so evenly and thoroughly; (3) there is no reflection of the sun from a water surface and no excessive collection of water at the base of the tree, or contact of standing water with the bark, all of which are believed to be causes of injury to the tree; (4) with the surface well prepared the distribution is almost automatic and may be left to itself for hours if necessary; (5) cultivation after irrigation can be begun sooner and the land brought to fine surface tilth at less cost than with any other system which would give equal moisture to the same kind of land.

Application of water by small furrows is greatly facilitated by special arrangements which are now almost universally used in California orchards worked by this system. One is the arrangement of the flume which is to feed the furrows and which extends along the high side of the area to be irrigated. These flumes are made either of

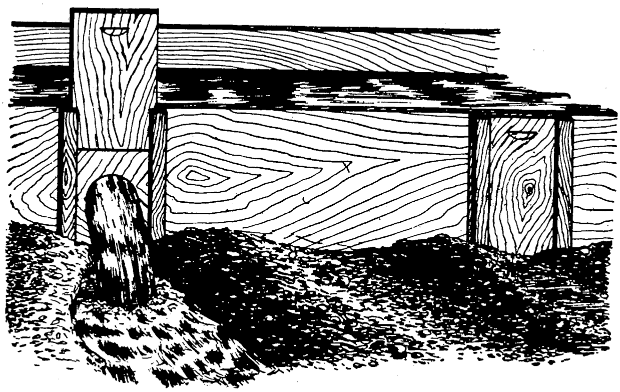

FIG. 8.—Flume for distribution of water in the furrow system.

cement or boards—the latter generally preferred, because easily made and being but partly below the surface, can deliver water to the furrows more easily than a cement ditch nearly flush with the ground surface; besides, openings and gates to adjust the amount of water allowed to escape are more easily contrived. Two things are essential to the even delivery at all openings of the same size: First, the flume should lie nearly level, using a drop now and then as necessary; second, the sides of the flumes should be all of the same height, so that there shall be the same water pressure above the center of the openings, which are round holes bored in the sides at a uniform distance from the bottom. If the flume is decreased in size as the distance increases from the starting point, make it narrower on the bottom, not lower on the sides. The round holes are usually opened and closed with metal slides moving in metal cleats tacked to the outside of the flume. These gates are best on the outside, because they are less liable to catch loose stuff in the water and they are more easily adjusted than if in the water on the inside. (Fig. 8.)

A good size for flumes is a uniform depth of 7 inches and widths varying from 16 to 8 inches. Two inch holes are good for the exits, though some use smaller. The distance between the holes will of course be the distance which is chosen as best between the furrows, which is usually about 2 feet. With young trees it is common to use fewer furrows and run them near the trees. As the trees spread, more furrows are used until the whole space between the trees is furrowed, except that the water is not brought as close to the trees as at first.

The furrows were made at first with a small single plow, but later several plows were attached to a frame, and now the "furrower" or "marker" consists of a frame carrying four or more plows, with two good-sized wheels several feet apart on a shaft ahead of the plows to steady them and regulate depth. The furrows are led up to the holes in the flume and the water is started.

There is a great deal to be learned by experience in handling water in the furrows, as by other methods. It is important that the lands should have equal areas; that the surface should be free from depressions, for there the water will collect until it rises above the furrows and finally runs together in a pond. The directions in which the furrows are run depend upon the degree of the slope; sometimes straight away from the flume; sometimes diagonally through the rows, giving less grade and allowing the water to soak in better. The admission of water depends upon the character of the soil. If it is light and coarse and takes water a little too fast, a large stream will rush through, carry off much soil, smooth the sides of the furrow, and make percolation less rapid afterwards; while on a rather heavy soil a strong rush at first would almost cement the sides so that there would not be soaking enough. Sometimes a larger stream may be given after the ground is wet than at first. After the small stream has reached the end a still smaller stream from the flume is continued for twenty-four hours or more. These are manifestly things that must be learned largely from experience and observation on the spot.

The water is controlled by regulating the slides in the flume, closing them down as nearly to uniform openings as possible. Some are able to do this so skillfully and to so gauge the stream to the receptive character of the soil that very little will waste at the lower ends of the furrows. This is, however, rather exceptional, and it is found that there will either be quite an outflow or that the trees at the lower side will not get enough water. Naturally the trees near the flume will get most water, as all the water goes by them and least of all passes the trees at the other end. To prevent loss, then, and at the same time to give the lowest trees more water it is common to put in a few large furrows across the lower end into which the water will run and soak away; or, what is perhaps better, the few rows at the lower end are checked and the water thus collected. Some arrange to have an alfalfa patch below the irrigated area, so that overflow water is turned to good account.

The small-furrow method on land adapted to it is used for everything which can be profitably grown in rows and cultivated after irrigation. All kinds of small fruits, vegetables, and field crops are thus open to the system, the number of furrows depending, of course, upon the distance between the rows and the degree to which the soil favors lateral seepage.

SUBIRRIGATION METHODS.

Introducing water below the surface to escape all the objections which may be urged against prevailing irrigation methods has long been the subject of invention and investigation. There is also a warrant for the effort in the fact that there are very large areas of profitable land in the irrigated region which are subirrigated either by natural underflow from adjacent higher grounds or from rivers or by artificial underflow from adjacent irrigated lands or the leaky ditches which supply them. The frequent mention of these situations as "subirrigated" has created the impression in distant parts that California was quite extensively using a subirrigation system. It is a misapprehension. California inventors have fitfully labored with the proposition for the last twenty-five or thirty years, but the matter has not yet passed the experimental stage and the acreage irrigated in this way is insignificant.

Subterranean distribution of water has, however, such obvious theoretical advantages in preventing loss by evaporation, in distributing water at a level which should encourage deep rooting, in reducing the frequency of surface cultivations, and possibly in automatic distribution of water which should be vastly cheaper than any kind of surface flow, that interest will always pertain to the proposition and efforts will be continually put forth to give it practical realization. For these reasons a brief characterization of subirrigation systems which have come under the observation of the writer will be given:

About twenty years ago the so-called "Asbestine system" was devised. It consisted of a farm reservoir in which water was collected to furnish a certain amount of pressure throughout a system of jointless pipes laid in trenches of suitable depth at whatever distances apart were determined by the facility with which water would seep laterally through different soils. These jointless or continuous pipes were made of cement and sand by a machine traveling in the trench, and this was resorted to to preclude the entrance of roots to the pipe, which was found to be an objection to the older systems of perforated tiles. At proper distances openings were made in the top of this pipe and a cement standpipe of larger diameter was saddled upon the continuous pipe at each of these openings, the standpipe rising to the surface and having a cover. When the water was properly admitted to the system from the reservoir it flowed in about equal volume from all the openings, soaked away at the bottom of each of the standpipes, and when the supply was shut off and the water disappeared at the bottom of the standpipes the roots could not reach any water that might remain in the pipes because of the air space surrounding the opening secured by the presence of the standpipe. Some experiments with this system were made but the cost of construction was seen to be so great that interest in it speedily declined. No demonstration was had that the system, properly constructed, would not successfully distribute water underground; in fact, enough was done to show that it would do so, and it is an interesting fact that in one case a small acreage thus piped was allowed to go unirrigated for a number of years because rainfall seemed ample for the growth of fruit, and was again irrigated by the system when a year of very short rainfall brought distress to the trees, showing that it remained free from roots. Still the cost of the system remains an apparently insurmountable objection to its introduction.

A system of distribution has been proposed which differs from the foregoing in placing the standpipes below the supply pipes and bringing the whole distributive system below the reach of the plow, which is an advantage in point of cultivation and a disadvantage in difficulty of seeing what is going on. The author of this system proposed to use tile to conduct the water from one of his standpipe cisterns to another, and trusted to their drying out between irrigations to remove all inducement to root entrance. He prescribed more pipe and more outlets than were contemplated under the earlier system, and would presumably get a better distribution of water, but the larger amount of cement construction and of excavation would probably make this system even more expensive than its prototype.

A system of similar aims, which has been patented, uses water from a reservoir through a system of iron pipes laid beneath the surface. At suitable distances the pipe has small holes on the under side; beneath each hole is a cast-iron chamber open at the bottom, and around this casting is a gravel pocket into which the water will flow and from which it will readily soak away into the surrounding soil. To irrigate trees of any kind a line of pipe is laid along a row of trees about 2½ feet from the trees, and opposite each tree a gravel pocket is made, and each one of these pockets holds about 5 gallons of water when full. When the water is turned on it continues to flow until the water pressure in the gravel pockets is equal to the pressure from the tank or reservoir, and then the water ceases to flow, only as the ground absorbs it. This system also occasions large outlay for materials and labor.

In another system of subirrigation three quarter inch pipes of iron carried the water to 2-inch iron standpipes, or hydrants, fitted with valves or plugs to regulate the flow. The water issues from these standpipes through small perforations in the sides. The entrance of roots to the pipes is prevented by the fact that when the valve below is closed the interior of the standpipe becomes dry.

Dr. S. M. Woodbridge, of Los Angeles, has in use an outfit which is less expensive than the foregoing system, because valves are discarded for slots cut in the stand pipes through a part of the threads which connect it with the T in the main pipe. Partially unscrewing the standpipe opens these slots and releases the water, and screwing it down again not only closes the slots and stops the water, but cuts off any roots which may be entering. Both systems rely for distribution of water upon a small release at a central point equally distant from four trees. Theoretically the objection would be that the supply would be too slow and scant except in very open soils, and in such soils there might be too rapid leaching away of the water to moisten the soil horizontally. On heavy soils lateral seepage from perforations, half the distance between the standpipes, say, 10 or more feet, could hardly be expected. Being automatic, however, and acting through a long period of time, if one has a suitable reservoir, there might be satisfactory amounts distributed in all except leachy soils.

The same comments would apply to the use by Dr. Woodbridge of a long line of iron pipe laid along the surface, with small openings at intervals discharging a trickle of water into each of a series of spade-holes placed in the center of the squares formed by four trees. By regulating the flow each hole can have just what will soak away without overflow. This is, however, really a very small basin system, with the basin placed as far from the tree as possible, which is a good place for it providing the water moves well laterally, and is sufficient in amount.

Thus far attention has been given to deep systems of subirrigation, such as would benefit the growth of trees. There are fewer difficulties attending such shallow system as might best serve gardens and small fruit plantations. There is reason to believe that, on certain soils, distribution through simple lines of tile laid near the surface may be more satisfactory than running water in furrows. This will be for shallow-rooting vegetables and berries, where the pipes are to be relaid and thrown out at short intervals of time. The entrance of roots in such cases is not a ruling factor. The distribution by connecting these lines of tile with a head ditch or flume is easily effected, and shallow cultivation need not be interfered with. But even in such case the cost of tile enough to cover any considerable area soon reaches high figures, and the labor of laying and relaying it is also expensive. It is doubtful whether the time will ever come when such systems and devices will replace well-regulated surface distribution and the cultivation which is associated with it, though for economy of water, and to escape the refractory condition which some soils assume upon surface irrigation, experimentation in this line certainly commends itself.

Distribution through tile laid upon the surface is available for shallow-rooting plants, and has been shown to be economical both of labor and water.[1] In an arid region, however, the prevention of surface stir-

[1] U. S. Dept. Agr., Farmers' Bul. 56.

ring of the soil is a decided objection to the system, unless the soil be very light and free from a tendency to bake. Surface applications not followed by stirring are not a substitute for cultivation, as already insisted upon in another connection. It is a common experience of beginners that plants may dwindle and fail, though water may be almost daily poured around them, on an uncultivated surface. Each new application seems to add to the compact and inhospitable character of the soil.

HOW MUCH WATER IS USED.

Thus have been hastily sketched the different ways in which water is applied to fruit trees in California, and it is hoped that this will be found suggestive to beginners in other parts of the country. A very interesting question is, How much water is used? It has already been claimed that this question can not be answered categorically because of the differences in exposure, soils, rainfall, and in the requirements of different plants. A careful inquiry recently conducted by the writer included the experience of scores of irrigators in different regions of the Pacific coast, and disclosed the fact that the amount of water applied actually differed even more widely than the theoretical computation based upon the influence of the variable factors mentioned would indicate. It is found that in addition to topography, mechanical conditions of soil, and variation in plant requirements, and at the same time somewhat determined by them, the factor of frequency intrudes, and, upon consideration of all factors, these brief deductions are suggested:

(1) With adequate depth and retentiveness of soil, 20 inches of rainfall, if duly conserved by good cultivation, may render irrigation unnecessary for deep-rooting, deciduous fruits.

(2) If the rainfall on such soil is inadequate it may be satisfactorily supplemented for such plants by winter irrigation, using a total depth of 6 to 12 inches, in from one to three applications, according to the receptivity of the soil.

(3) Also, for such soils for such plants, the same results can be secured by summer irrigation with from 3 to 6 inches of water, divided into two or three applications.

(4) On deep, leachy soils for such plants neither heavy winter rains nor winter irrigation will suffice, and a monthly application of 2 or 3 inches of water from May to August or September may be required.

(5) Even on deep, retentive soils, as well as on coarse soils, shallow-rooting deciduous plants, bearing what are called "small fruits," may require fortnightly or even weekly applications amounting to 4 inches a month during the dry season.

(6) On shallow soils of retentive character even deep-rooting trees may require 2 inches monthly, from May to August, while on shallow, coarse soils 50 per cent more water may be necessary.

(7) On shallow, coarse soils shallow-rooting small-fruit plants may fail through heat and drought in spite of any frequent use of water

which is commercially practicable. Sprinkling and mulching may make the plants satisfactory for home use.

(8) Evergreen fruit trees, including citrus fruits, require about 50 per cent more water than deciduous fruits would require upon the same soil and in the same location, except that the olive will thrive with approximately the same water which satisfies a deciduous fruit tree, but it must be available later in the season, as the tree develops its fruit later.

These deductions are not intended to be indications of what is necessary to the trees; the quantities given are general statements of what is used by those who have bearing trees and secure good crops of marketable fruit.

AFTER TREATMENT OF IRRIGATED LAND.

In most parts of the irrigated region clean culture is practiced during the growing season, though there is another policy which seems to suit local requirements better in some regions, as will be noted presently. This clean culture is undertaken for two main reasons. One is moisture conservation, which has been pointedly suggested in the previous discussion of the interrelations of irrigation and cultivation. Cultivation is undertaken, then, to reduce the irrigation requirements; to retain the added moisture for the use of the plant. Experience amply teaches that this is successfully done, and investigation has given accurate measure of conservation, both as against evaporation and against exhaustion by the roots of weeds and intercultures of crops.[1] Just as barely adequate rainfall may be rendered amply adequate by clean and frequent summer cultivation, so irrigation water may be reinforced in the duration and sufficiency of its effects by the same policy.

But another and important office of cultivation in connection with irrigation lies in the maintenance of a condition of tilth which facilitates a proper degree of aeration and free root extension. Irrigation, even in its wisest application, has a tendency to compact any soil which is capable of compacting, and few can defy water settling. Compacting promotes evaporation and subsequent sun heating, and the resulting dryness and undue heat, as well as the density of the mass itself, restrains root development. Consequently it is a universal conclusion that, with a bare surface, soil stirring must follow irrigation just as soon as the soil comes to a good working condition. What the cultivation shall be depends upon the nature of the soil. Winter irrigation is almost always followed by a good plowing, and by a good harrowing also, unless considerable rainfall is to be expected afterwards. Summer irrigation is followed by stirring with whichever of the many forms of cultivators is found by local experience to be the

[1] U. S. Dept. Agr., Farmers' Bul. 87.

best pulverizer for the particular soil, and which secures, with the least labor, fineness to an adequate depth, for it is plain that in the thirsty air of the arid region the earth mulch must be somewhat deep, as well as fine, to protect the firm layer from loss by evaporation.

COVER CROPS IN THE IRRIGATED ORCHARD.

Successful irrigation is not conditioned upon clean cultivation; in fact, it may be quite otherwise. Cover crops are sometimes of advantage. Recent practice in some parts where irrigation water is abundant beyond the requirements of the trees, is to grow alfalfa in the orchard. Being a deep rooting legume, it may be of advantage to the trees in the presence of ample moisture, while with scant moisture it would rob the trees and practically ruin them. In the hot irrigated valleys of Arizona a cover crop of alfalfa reduces the soil temperature, prevents the reflection of heat which occurs from a light-colored soil surface, and is said to insure thrifty young trees where clean culture destroys them. In cooler parts of the arid region, as in the mountain valleys of northeastern California and in Idaho, alfalfa is also grown in irrigated orchards. These facts are of wide significance as showing that irrigation may be found of benefit even where clean culture may not be thought desirable. It is certainly reasonable that if a cover crop is grown at all it should be attended by the surety that the trees shall not suffer for moisture, and they unquestionably do sometimes suffer seriously under old turf, even in lands of summer rains.

This view is wholly apart from the subject of exhaustion of soil fertility by intercropping. Of course, compensation for that depletion must be made by use of fertilizers, and whether the intercrop secured yields a profit upon such investment is a calculation foreign to this discussion. The purpose simply is to emphasize the fact that on rich soil ample irrigation can produce good fruit on an intercropped orchard, and it can do the same on a pastured orchard, but the height and form of a cow-pruned fruit tree is totally abhorent to present ideals.

A cover crop and an intercrop are, however, somewhat different things. The growth of a cultivated crop between the rows of fruit trees is permissible if the land is rich, and moisture, either by rainfall or by irrigation, is ample; but experience has shown that such a crop is only profitable while the trees are very young. As the trees expand they repress the growth of the intercrop below the profit mark, and give no further inducement to the grower to longer endanger the future of his trees by dividing their sustenance with the intercrop. On the other hand, a cover crop, if it be a legume, may reenforce the humus in the soil. One of the objections to continuous clean culture in the arid region is the tendency of the soil to lose humus and to become lifeless and refractory. The growth of clovers, peas, and other hardy legumes during the winter season, when the moisture is usually abundant, is being widely resorted to for the purpose of restoring humus. The summer growth of tender legumes with ample irrigation is therefore, for this reason, as well as for lowering the soil temperature and escaping other effects of excessive temperature, worthy of consideration if water is ample enough to support the cover crop and the trees.

Clearly where such practice is advisable the irrigation method must be suitable. If the land is nearly level, low check levees on contour lines will restrain sufficient water and not interfere with the use of the mower. Such contour checks may inclose a considerable number of trees. With greater slope the square check system inclosing a single tree may be necessary, or flooding down the spaces between the trees, with a low levee along each row, may be the most available system, except in small orchards where pipe lines, hydrants, and sprinkling may be used.

MINOR RESULTS OF IRRIGATION.

It is obviously impossible to include in this general sketch many of the minor results of irrigation which have been demonstrated by half a century of experience in the arid regions, but a few may be noted:

In parts of California light frosts are likely to occur while citrus fruits are ripening and after the deciduous fruits have bloomed and set their fruit. This is from December to May. There is no hard freezing, but even a slight drop below the freezing point may occasion considerable loss of fruit. It has been found that over ground with a wet surface fruit may escape injury while that near by over a dry surface may be destroyed. For this reason irrigation water is used to prevent frost, and it has been found effective even when the mercury falls to 27° F., providing this temperature covers only a brief interval. If the mercury falls lower or remains too long at the point named, injury will result in spite of the presence of water, unless more effective methods of protection are resorted to.

To a measurable extent irrigation is found to hasten fruit ripening. In some cases several days have been gained with early varieties by giving water just as the fruit was getting good size. The same varieties near at hand proceeded more slowly without this stimulus.

The application of cold water to the roots of growing plants is very undesirable. Nearly all water derived from subterranean sources is improved by exposure to the sun, either by standing for a time in a shallow reservoir or traveling some distance in a shallow stream. Exposure to sun heat can not make the water too warm.

Irrigation performs a host of small services. In the nursery the budding season is lengthened because a run of water will cause the bark to slip later in the season. In the English walnut orchard the nuts will be more readily discharged from the husks if an irrigation is given a little in advance of the dropping time. Within certain limits fruiting can be timed by irrigation and succession secured. This is especially true of small fruits. Strawberries can be made almost constant bearers in suitable thermal situations and can have two main crops in the summer even where the winters are too cold for fruiting. Raspberries follow the same course, and ever-bearing blackberries are the ruling varieties in the warmer parts of the irrigated region. Of course these performances of plants are dependent upon temperature conditions as well as moisture conditions, and upon the length of the growing season which the irrigated semitropical region enjoys; but the fact remains that the forcing summer heat of the more northerly regions of the country could accomplish far more for the grower if by forethought and wise provision he should arrange to have that beneficence always attended by ample moisture. This is evidently one of the great works of the future.

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