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The Management of Sandy Soils Under Irrigation

By
H. K. DEAN

CORVALLIS, OREGON

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CONTENTS

SUMMARY

This publication embodies the results of experiments and recommendations on the management of sandy soils under irrigation from the work of the Umatilla Branch Experiment Station.

If light soils are to be permanently farmed under irrigation a balanced system of agriculture should be practiced, with rotations and enough livestock to consume the feed produced on the farm.

Light soils, because of their low water-holding capacity, require preparation of the land in the best possible manner and economical methods for the application of water.

A comprehensive study of the tract and plans for its ultimate complete reclamation should be made prior to beginning work.

Excessive grading exposes the subsoil, which is low in organic matter and of coarser structure than the surface, and results in greater difficulty in handling the soil and in reduced crop yields.

The water-distribution system should be so constructed that large heads of water can be used. Use of gates for turning the water onto the land is much more satisfactory than cutting the ditch banks.

Light soils are most economically irrigated with large heads of water. The border method has been found to be the most suitable because it is an economical means of preparing land for irrigation, because economical applications and uniform distribution of water can be secured, and because the labor of irrigation is reduced to a minimum.

The width, length, and shape of borders depend upon the character of the soil, the slope of the land, and the head of water available.

Strawing prevents the soil moving until the cover crop has become established. Rye has been found to be the most satisfactory nurse-crop.

The most economical interval of irrigation for alfalfa on medium sandy soil is once in two weeks.

Eight tons of manure to the acre increased the yield of hay 1.33 tons, while 32 tons increased it 2.29 tons, much larger returns per ton of manure being secured from the lighter application.

Returns from mixed grass pastures on the finer sandy soils are frequently equal to if not higher than returns from hay land. An area of grass pasture will produce approximately as much feed as the same area in alfalfa and can be used without harvesting cost. Seepage ground not water logged is ideal for grass pastures.

The Management of Sandy Soils Under Irrigation

The work of the Umatilla Branch Experiment Station during the past twelve years has been largely the investigation of the best methods of establishing permanent and profitable agriculture on the sandy irrigated soils of the Columbia Basin in Oregon and Washington. The experiments have chiefly embraced crop testing, soil moisture and irrigation methods, and the improvement of the fertility of the soil. The information embodied in this publication is the result of these investigations and observation of the best methods employed by the farmers on the Umatilla Project. The soil, climatic, and topographical conditions under which the Umatilla Branch Station is working are typical of those of eight irrigation projects, comprising approximately 275,000 acres, and of several hundred thousand acres of raw land in the Northwest which will be brought under irrigation in the future. The areas in Oregon are shown in Fig. 7.

The farms on irrigation projects in the West have been used at first for cash crops rather than livestock, and diversification has not come until later. The average settler has not had the capital to establish herds of livestock and often he has been forced to secure profits from part of the farm with which to develop the remainder. The cash crop of most of the irrigated lands in the Columbia Basin has been alfalfa. During recent years on the Umatilla Project, which is fairly typical of the area, approximately 80 percent of the crop income has been derived from alfalfa and a large percentage of this crop has been sold and shipped off the project.

Light, arid soils are naturally deficient in organic matter and plant food, and if fertility is to be maintained and increased rotations should be established and provision made to feed the crops on the land. Fortunately, alfalfa is a crop which may be readily converted into cash on the farm by feeding to livestock, so that the transition to a rational system may be readily made. Livestock adds greater diversity and stability to the farm system.

The soils of the Umatilla Project range from fine sand to medium sand with some small areas of coarse sand. The experiments here reported were conducted on medium sandy soil. The recommendations are primarily applicable to medium sandy soils, but consideration has been given to both finer and coarser types.

This publication is issued for the purpose of making readily available the best information to date on the development of light soil under irrigation.

PREPARATION OF LIGHT SOILS FOR IRRIGATION

Light soils, because of their low water-holding capacity and open texture permitting rapid percolation, require special methods of irrigation. The principle is to use large heads of water and flood the land rapidly so that the root zone of the plants only is filled with water. The successful use of a large head of water requires careful preparation of both the irrigation system and the land. The border method has been found to be the best means of securing this result because large heads of water may be handled in borders to make light and uniform applications and because under this method land is easily and economically prepared for irrigation.

Land should be thoroughly prepared for irrigation when it is first put in; it is cheaper to prepare properly than to attempt to irrigate poorly prepared land and then be compelled to work it over. The difference in the cost of poorly prepared and well prepared land is not great and is a small portion of the total cost. The extra day or two required to put the land into the best possible condition is the most valuable part of the expenditure and pays good returns every year in economy of water and labor of irrigation. Any piece of land worth preparing for irrigation is worth preparing in the best possible manner.

PRELIMINARY STUDY OF THE LAND

The first step in the reclamation of a piece of arid land should be to make a study of the entire tract and a comprehensive plan for the irrigation. It is a serious mistake to plan and put in one part of the system without considering the whole tract as it will often be found that the first part will have to be changed to coincide with the whole. If the settler is inexperienced it is advisable to work first on the parts easiest to prepare, which will usually be the smoothest areas, so that experience may be gained without undue waste of labor.

A study of the topography of a tract of land will reveal the location of the best-lying land. Land requiring the least expenditure should be graded first, as returns will be most rapid from it. Investigations of the soil and subsoil will reveal the best land and perhaps the presence of cemented gravel, boulders, or bed rock. It is especially important to investigate the subsoil conditions before beginning deep cuts in grading down knolls or ridges. Excessive grading should be avoided so far as possible as it results in exposing the coarser subsoils which are low in organic matter and have low moisture-holding capacity. Where the subsoil has been exposed, it is difficult to secure stands and yields are materially decreased. A portion of one of the Experiment Station fields which was heavily graded eleven years ago still shows plainly the effect of grading by producing poor crops although it has been heavily manured and has had several cover crops turned into it. On one of the other fields the average yield of alfalfa on a heavily graded portion for 5 years has been 3.86 tons an acre; on the medium graded portion, 4.06 tons; and on the lightly graded portion, 6.00 tons. These figures show a very marked relation between the amount of grading and the yield of hay and further show that the effect of grading may be pronounced for a number of years.

Failure in the reclamation of light arid soils has often been due to not having recognized the danger to ditches, graded land, and tender crops from the erosive action of wind-moved soil. It is safe to remove the brush over large areas, but the soil should not be disturbed until just prior to grading and then only in comparatively small areas which may be graded rapidly and covered with straw, as described later.

DISTRIBUTION SYSTEM

After the native vegetation has been removed the next step is to plan definitely and lay out the distribution system, which should be done with the idea of providing the proper means for the most economical distribution of water to all parts of the tract. It is a common mistake to lay out and construct a system for a part of the tract without regard for the irrigation of the remainder; later it is found both difficult and costly to abandon the system and begin anew. Frequently the distribution ditches are constructed altogether too small for economical irrigation.

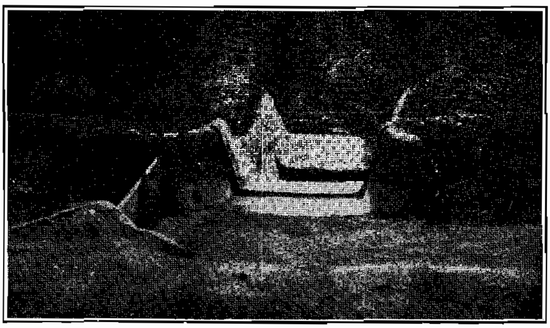


Fig. 1. A combined diversion and drop box made of concrete plastered against the ditch. Flood gates are made in the same manner. Concrete structures are cheaper than those of lumber and are permanent.

Heads and Grades. *The economical use of water on sandy soils demands the use of large heads of water which will flow over the land rapidly.* Heads of from 3 to 5 second-feet are generally considered large enough to be economical and still of such size that they can be readily handled by one man. Table I of the appendix gives the carrying capacity of earth ditches. The main laterals should be built with a fall of 0.50 to 0.75 foot per 1000 feet and 3 feet wide on the bottom. A ditch this size will carry from 2.5 to 6 cubic feet per second depending upon the depth of water in the ditch. The distributing ditches in the field need not be so large, 2 feet wide on the bottom being large enough, but they should have a fall of 1 foot per 1000 feet of ditch to carry the same head. *No part of the irrigation system should be constructed so small that it will not carry the entire head of water.*

The capacity of a ditch varies as much with the grade as with the size. The smaller the volume to be carried the greater the grade must be to produce a given velocity. Grades of 0.50 foot to 0.75 foot per 1000 feet for large ditches and 1 foot per 1000 feet for small ditches will produce a velocity of 1 foot per second. Velocities in excess of 1 foot per second on light soils result in washing the ditch bottom, hence should be avoided.

Drops and Turnouts. When it is necessary to carry ditches down excessive slopes the velocity may be decreased so as to prevent scouring by the insertion of *drops of wood or concrete.* A combined check gate and drop built of concrete is shown in Fig. 1. All check gates and drops should be made as wide as the maximum width of the water in the ditch so the velocity of the water will not be increased and cause scouring. The grade of the ditch between drops should be the same as

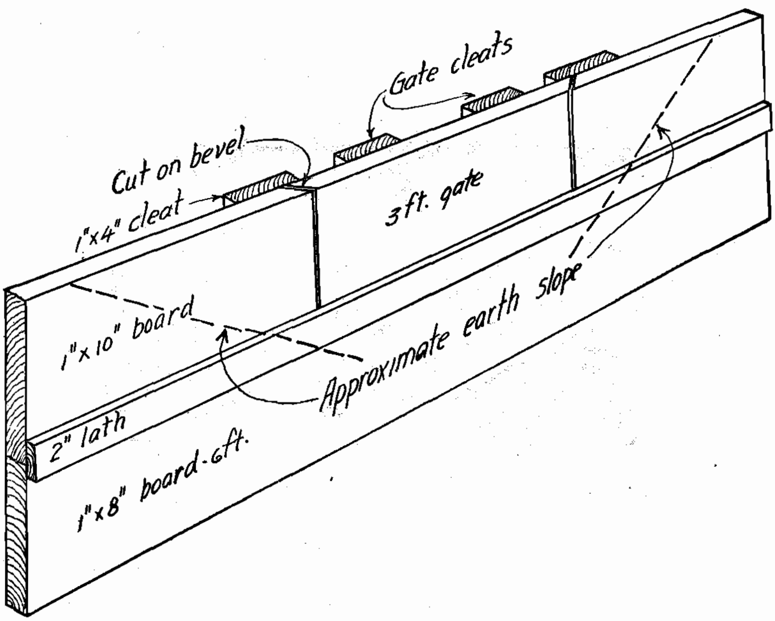


Fig. 2. A wide ditch gate which reduces the velocity of the water and therefore the washing, and which requires little lumber. Similar gates are used as check gates by placing them across the ditch.

in the open ditch. On very steep slopes a chute of wood or concrete or a pipe line is cheaper than a series of drops. If such an installation is necessary to drop the water from one ditch to another in the open field it should be placed underground so as not to interfere with cultivation and harvesting.

A form of turnout which has been found easy to construct and which requires a minimum of lumber is illustrated in Fig. 2. It is important to have the turnouts wide so that the water will flow out in a slow stream and thus avoid a rush that will cause erosion. Wide turnouts are constructed also by plastering up the banks as in Fig. 1. If the land outside the ditch is slightly higher than the ditch bottom the drop and stilling basin of Fig. 1 may be omitted. Unless the ditch has been kept high to go over depressions the bottom should be about three inches lower than the land. The turnout should be placed so that it is higher than the ditch bottom and lower than the land. When this is done the water will be compelled to rise slightly as it goes out of the ditch and the velocity will be checked so there will be no washing.

METHODS OF IRRIGATION

During the early years of development on the Umatilla Project furrow irrigation and wild flooding were generally used. The furrow irrigation method was undesirable in that the head of water was divided so that the loss from percolation below the root zone was excessive and it was difficult to reach the lower ends of the fields. The wild flooding was unsatisfactory because parts of the field were irrigated more than once and the higher portions were not irrigated. These objections were overcome by the border method of irrigation, first investigated and recommended in the Columbia Basin by the Umatilla Branch Experiment Station. By this method the head is not divided and can be forced over the land quickly without excessive percolation loss. The duplication of irrigation is overcome by dikes which control the water and when a border is properly constructed there are no high spots which are difficult to irrigate.

THE BORDER SYSTEM OF IRRIGATION

In the border method of irrigation the land is laid out in strips which run down the steepest slope of the land away from the head ditch and are level from side to side and are separated by low dikes which control the water from spreading sideways.

Application of Border Method. While the border method in the Northwestern states has been used almost exclusively on light soils, in other states it has been found to be an economical system on different soil types. In California, Arizona, and Utah the border practice as to size and the head of water used varies with the soil type. On sandy loam soils borders are 30 to 50 feet wide, from 330 to 1320 feet long, heads of water from 5 to 20 second-feet being used. On clay soils the width is from 40 to 100 feet, the length from 660 to 1320, heads from 3 to 5 second-feet being used. The small heads on heavy soils are economical because more time is required for the water to soak into the soil. In some instances on the heaviest soils the heads are divided so as to give time for percolation.

Border Practice in the Columbia Basin. On the Umatilla Project, where the border method has come into very general use largely through the efforts of the Experiment Station and the local representative of the Office of Demonstrations on Reclamation Projects of the United States Department of Agriculture, borders are constructed from 20 to 40 feet wide and from 100 to 250 feet long, heads of from 3 to 5 second-feet being used. As a result of the unusual success secured on the Umatilla Project, the use of the border method is rapidly spreading to the other light soil projects of the Columbia Basin. At eight points in the Columbia Basin in Oregon and Washington demonstrations have been held by the Experiment Station in cooperation with the county agents. Borders which had been previously laid out were irrigated and talks were given on the investigations of the Experiment Station and methods of preparing the land. These meetings have been attended by nearly a thousand farmers who have seen the value of the system and are using it on their own places.

Advantages of the Border System. The advantages of the system are: (1) It is a comparatively economical means of preparing land for irrigation. (2) Economical applications of water can be made by running the water over the land quickly, thus avoiding deep percolation. (3) The distribution of water is uniform. (4) The labor of irrigation is greatly reduced as compared with the flooding or furrow methods. Fig. 4 shows the even distribution of water possible when the border method is used.

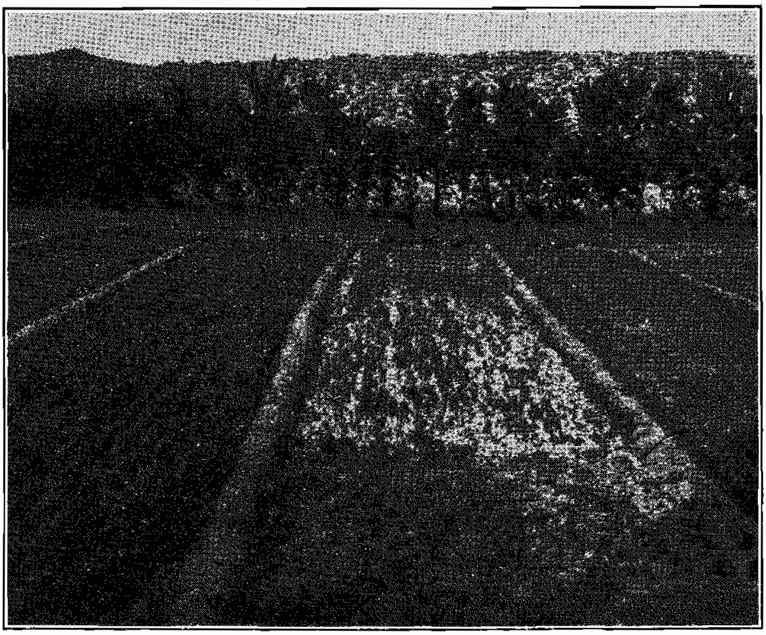


Fig. 3. The distribution of irrigation water is uniform when the border method is used.

Irrigation Experiments with Borders. The border irrigation experiments which have been conducted consist of a length-of-border and a width-of-border trial.

Length of Border. The length-of-border experiment has borders 100, 175, and 250 feet long, by 22 feet wide.

The average amount of water used in the length-of-border experiment was only slightly more on the 175-foot border than on the 100-foot border, but considerably more water was used on the 250-foot border than on the 175-foot border.

The 100-foot border required 4.18 acre-feet, while the 175-foot border required 4.86, or only .68 acre-foot more than the 100-foot border. The 250-foot border required 6.45 acre-feet, or 2.27 more acre-feet, showing very definitely that the additional 75 feet required so much water that the long border was not economical.

Width of Border. The width-of-border experiment has borders 20, 25, 30, 35, and 40 feet wide and 200 feet long. The amount of water in acre-feet per acre required to irrigate the 20- and 25-foot borders was equal, and the 30-foot border did not require excessive amounts of water; but the 35- and 40-foot borders required more water than is consistent with good irrigation practice. The amounts of water used are illustrated graphically in Fig. 4. The amount of water required for the single irrigations was in the same proportion as the total amount of water used.

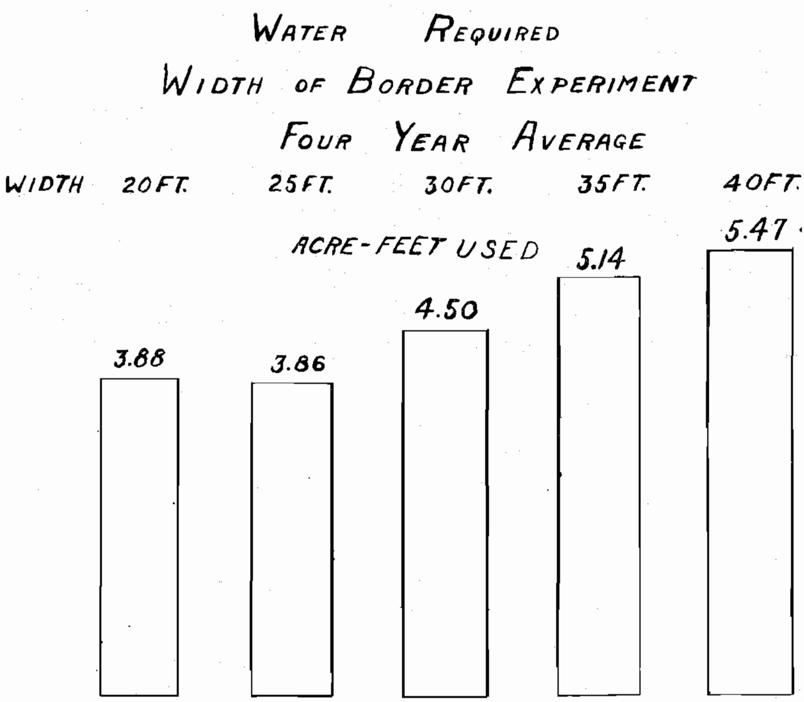


Fig. 4. The water required to irrigate 20- and 25-foot borders was equal and the 30-foot borders did not require excessive amounts, but the 35- and 40- foot borders used more water than is consistent with good irrigation practice.

Size of Border. The width, length, and shape of borders depends upon the character of the soil, the slope of the land, and the head of water available. Percolation is greater when the soil is coarse than when it is fine; borders should be comparatively small on coarse soils so as to irrigate quickly. The danger from excessive irrigation and consequent water-logging of the soil is particularly great on shallow soils and borders should be narrow and short. On land with considerable lateral slope borders should be narrow so as to avoid too much difference in level from one border to the next. On steep land the borders should be constructed short so as to irrigate quickly thus preventing washing. If the head of water available is over three second-feet the water is forced over the land to a certain extent by the push of the stream behind so that the borders can be made somewhat larger than they could if the head was smaller.

Fig. 5. Borders on land of smooth character are of regular width and direction. They require a minimum of grading.

On land with rough topography much grading and consequent reduction of fertility may be saved by making the borders conform to the land as shown in Figs. 6 and 8, which are explained more fully below, rather than grading to make them of regular shape. Fig. 5 shows borders on land of regular character.

The length of borders commonly used on light soils varies from 70 feet on very coarse soil or steep land to 300 feet on the finer soils with moderate slope and good depth. The ordinary widths of borders used are from 20 feet on steep or coarse soils to 40 feet on gentle slopes and fine soils.

The size of the border must be governed by the type of soil, the slope of land and by the head of water available. *Every piece of land has its peculiar problems and the manner in which it is to be laid out will depend on these factors, but the foregoing results as to size should be kept in mind.*

Slope of Land for Borders. The ideal slope of land for borders on light soil is a fall of a foot or a foot and a half per 100 feet of run, but they are successfully used on land both flatter and much steeper than this. Where the grade is more than 4 to 6 feet per 100 feet borders are successful only where special care is given to prevent washing. Borders are being used, however, on land having up to 10 feet fall per 100, but on such steep land it is necessary to disk in straw and have a good cover crop established before attempting irrigation. Unless the farmer is willing to give this special attention to steep land he had better parallel the head ditch with subditch having lath boxes, and irrigate with furrows 1.5 to 2 feet apart after the land has been "strawed" and seeded to rye. When the rye has grown to 2 to 4 inches the alfalfa can be seeded immediately after irrigation. When the alfalfa has become thoroughly established the furrows can be discontinued and the land flooded.

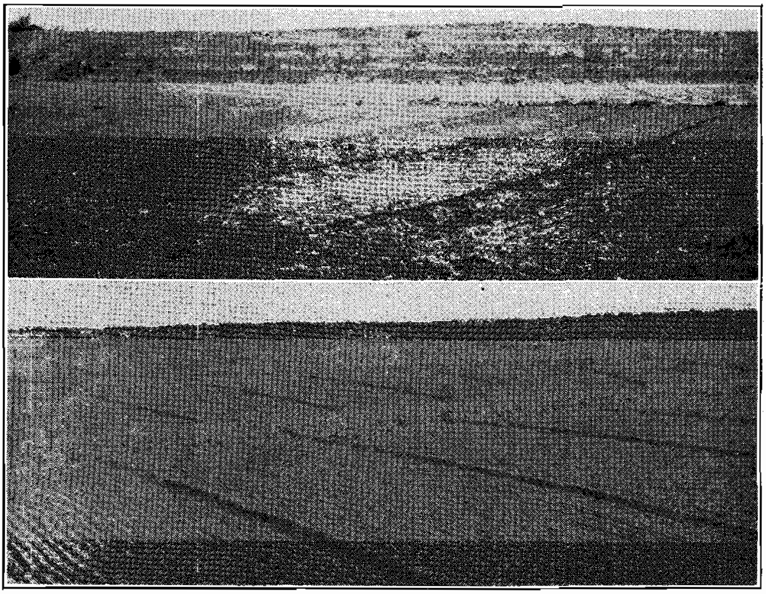


Fig. 6. Borders on land of irregular character are of varying widths and directions. Making the borders fit the land, instead of grading the land to make regular borders, saves much grading.

Grading the Borders. When the distribution system has been located and marked, preferably by plowing out one or two furrows, the next step is the grading of the borders. It is advisable to grade a practically level bench 15 to 30 feet wide at the lower side of the ditch and along the heads of the borders. The water coming out of the ditch onto this bench will be spread out in an even sheet before it starts down the border. Water which is spread on this bench will run over the border much more evenly and will not have such a tendency to run into one stream and wash. The bench is particularly important on steep land.

Location of Dikes. Fig. 8 illustrates the method of laying out the borders to fit the land so that there will be a minimum of grading after the bench has been leveled and the land smoothed. Two or three level

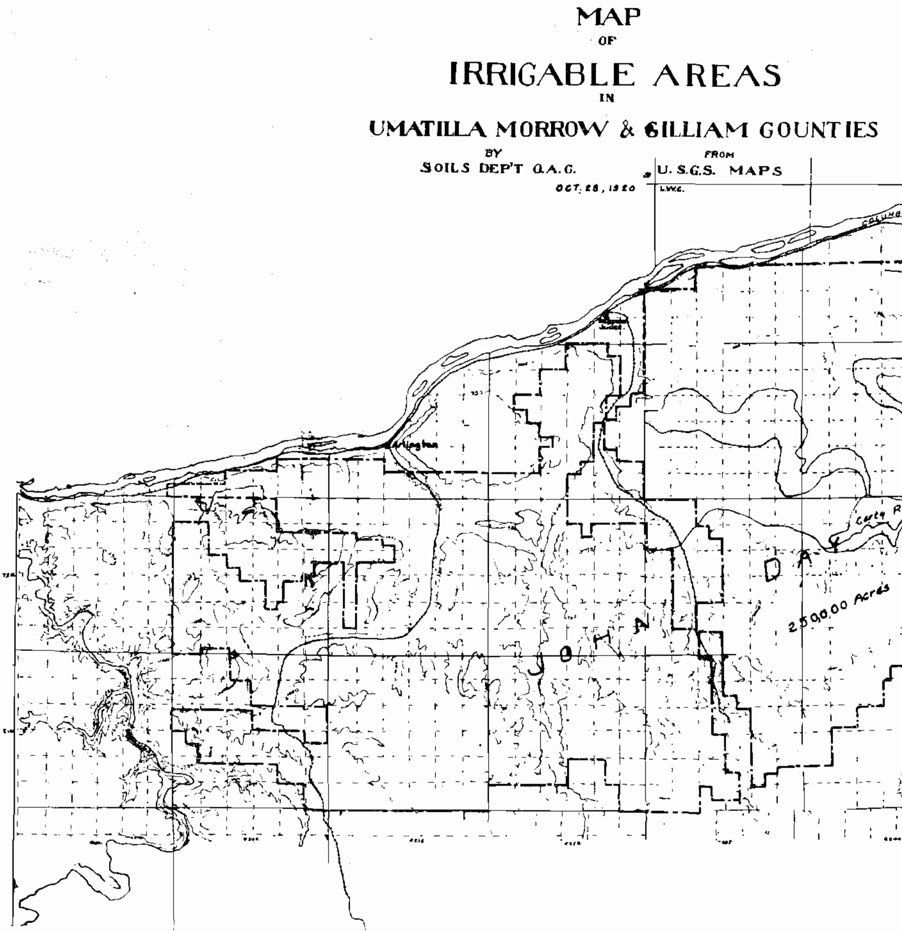
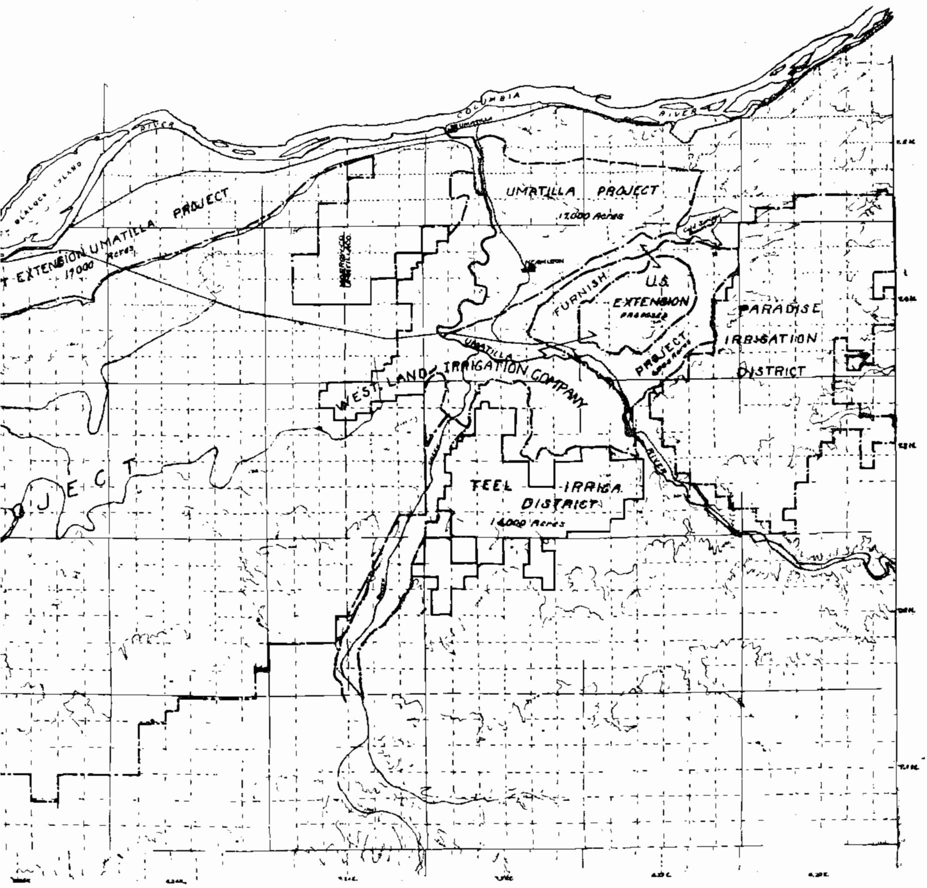


Fig. 7. Map of the sandy soil areas of the Columbia Basin in Or



ch the results of the Umatilla Branch Experiment Station apply.

contour lines are staked out across the field as indicated by X. When the dikes run down the field at a right angle to the contour lines the method leaves between each two dikes a border which is approximately level. In other words, the dike line at a right angle to the contour line runs down the steepest slope and gives an average of the two slopes. The points located within the circles in the chart are exactly at a right angle to the contour line, but since it rarely occurs that the dots all fall on the dike line the dike is constructed so as to average the points. Where a ditch goes around a depression as at the left of the illustration, Fig. 8, the borders will be wider at the top than at the bottom and where it goes around a point as in the right center they will be narrower at the top than at the bottom. The contours at the extreme right were almost straight so that the border was of practically equal width at top and bottom.

METHOD OF CONSTRUCTING BORDERS TO CONFORM TO IRREGULAR LAND

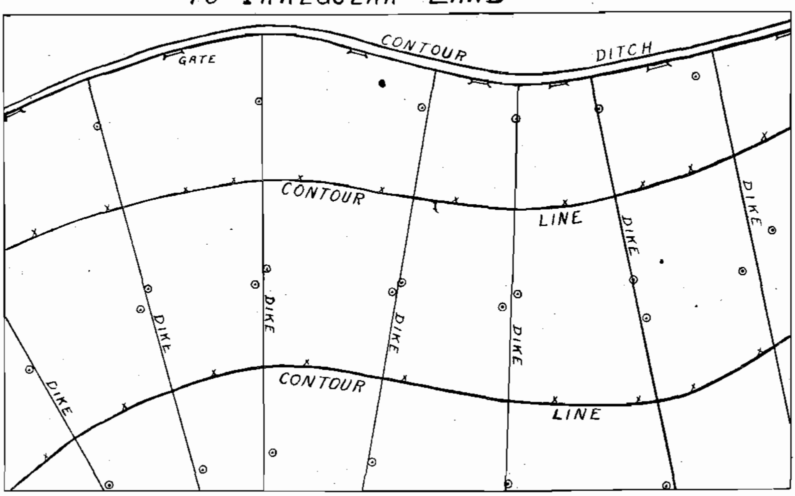


Fig. 8. On land of rough topography much grading and consequent reduction of fertility may be avoided by making the borders conform to the land rather than grading to make borders of regular shape.

Construction of Dikes. The dikes should be built 1½ to 3 feet wide and 1 to 1½ feet high when first constructed. Dikes are constructed by various means such as throwing plow furrows each way or with a disk harrow inverted so as to throw the earth in; or with a large V, 10 to 12 feet long and the same width, with an opening 2 feet wide at the rear end. When the dikes have been constructed the land between them is leveled with a fresno scraper and then floated. Particular care should be taken to fill the depression from which the dike material was collected.

The final test of the border is made by running the water over it and if any high spots or depressions are found they are smoothed out. As soon as the grading has been completed the land should be seeded and covered with straw.

Prevention of Soil Movement by Wind. A method which has been found successful in holding open soils against the winds is that of covering with straw at the rate of ½ to ¾ ton an acre, which is about as thin as it can be spread. The straw is disked into the soil with a disk harrow with the disks set straight as illustrated in Fig. 9. The disked-in straw prevents the strong wind from reaching the soil and moving it before the cover crop has become well established. The constant rasping action of the wind in moving the loose dry grains during heavy winds soon cuts off the young plants at or near the surface of the ground.

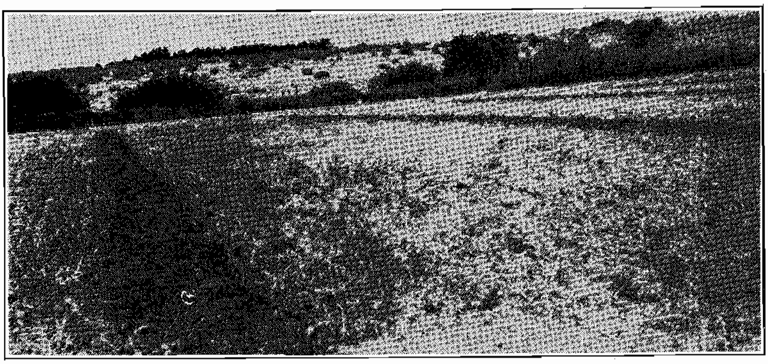


Fig. 9. Well constructed borders. The land is shown covered with straw disked in to prevent the soil from blowing; the dikes are covered with manure.

Cover Crops. Rye has been found to be the most suitable grain to plant as a nurse crop on new land because if given sufficient moisture the plants will survive, unless completely covered or almost blown out by the roots. Rye can be grown in colder, more exposed places as it germinates quickly and will grow at temperatures a few degrees above freezing when other grains would be practically at a standstill, and it will thrive on soils of lower fertility than other grains. Wheat, barley, and oats, when young, seldom survive under these unfavorable conditions and should not be used on raw soils. Their use is sometimes permissible on ground which has grown alfalfa, as the organic matter turned under holds the soil from blowing. If the growth of the nurse crop becomes so rank as to check the growth of the alfalfa it should be clipped. Clipping also reduces the water requirement of the alfalfa and tends to force deeper rooting. The straw and rye will prevent washing by the water as well as erosion by the wind.

Time and Method of Seeding. The most successful stands of alfalfa are secured by seeding in the spring in March or April or in the late summer from August 1 to September 15. Frequently good stands are secured during the summer months, but irrigation is necessary at not longer than one-week intervals to keep the young plants alive. The tendency recently has been more to fall-seeding than spring-seeding; the weather becomes more favorable for the young plants, while in the spring the moisture requirement continually grows higher. Stands are occasionally secured as late as October 15, but the plants usually do not have time to become established so as to withstand the winter.

Alfalfa should be seeded with a drill at the rate of twelve to fifteen pounds an acre. It is always advisable to use a drill in preference to broadcasting and harrowing in; the seed is thus planted to a uniform depth, one to three inches being deep enough to secure favorable moisture conditions. The drill should always be run parallel to the ditch across the borders so that the water will not collect, run down the drill marks, and wash.

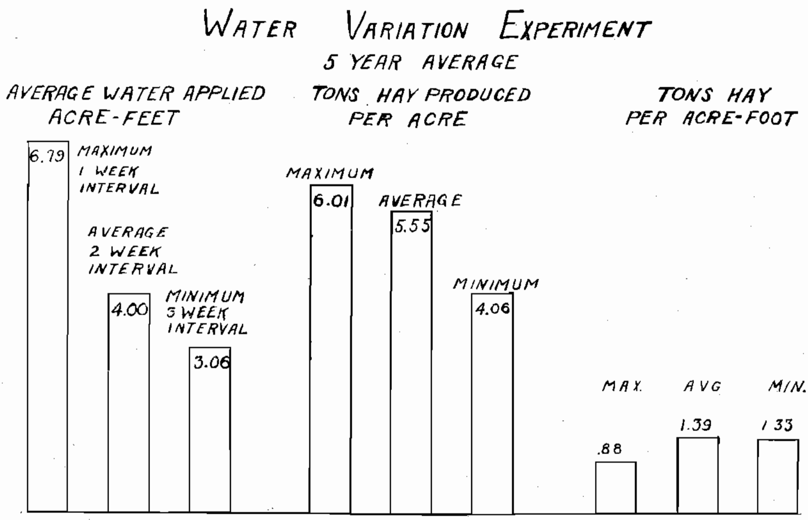


Fig. 10. The field irrigated once a week produced slightly more hay than that irrigated once in two weeks, but the additional hay secured was not enough to offset the additional labor involved in irrigation and the additional water charge. The highest duty of water per acre-foot was secured when water was applied once in two weeks.

IRRIGATION OF LIGHT SOILS

Light soils, because of their open structure, which permits rapid percolation, require special methods of irrigation. *The principle is to flood the land rapidly with large heads of water, thus making an economical application of water by preventing deep percolation.* The border method is the best means of handling water to secure this result.

RESULTS OF IRRIGATION EXPERIMENTS

Amount of Water. The results of the soil-moisture work of the Umatilla Branch Experiment Station have shown that *medium light soils have a moisture-holding capacity of approximately one acre-inch per acre-foot of soil.* In other words, one foot deep of soil on an acre will hold enough moisture to cover that acre one inch deep. The depth of soil from which the roots of the various crops draw moisture should be carefully ascertained and the depth of water applied at each irrigation so governed that there will be little or no percolation below the root zone. On the average soil of the Umatilla Project the roots of alfalfa take moisture from a depth of four to five feet and the water applications on such medium light soils should be limited as far as possible to four or five acre-inches. When land has been properly prepared and irrigation streams of not less than four second-feet are used it is easily possible to make applications of not to exceed four acre-inches.

Frequency of Irrigation. For five years an experiment has been conducted to determine the most profitable frequency at which to apply water to alfalfa and the most economical amounts to apply. This experiment has continued long enough and the results have been uniform enough to warrant very definite conclusions as to the amount of water required and the proper interval of irrigation on this soil.

Water was applied at one-, two-, and three-week intervals to plots of alfalfa which otherwise had uniform treatment. The figures given below are the average of five years results. Fig. 10 represents graphically the water applied, the hay produced, and the tons of hay produced per acre-foot of water. The land irrigated at one-week intervals received 6.79 acre-feet and produced 6.01 tons of hay per acre; that irrigated at two-week intervals produced 5.55 tons of hay with 4.00 acre-feet of water; and the land irrigated at three-week intervals produced 4.06 tons with 3.06 acre-feet of water.

During one year of the experiment over 4,000 soil-moisture samples were taken from the field before and after irrigation to ascertain the proper depth of water to be applied at each irrigation. It was found that the soil was capable of holding approximately an acre-inch of water in each acre-foot of soil as mentioned above, so that the applications of water were afterwards limited as far as possible to four acre-inches, which wet the soil to a sufficient depth for plant roots.

The duty of water per acre-foot is the amount of hay produced by an acre-foot of water and is determined by dividing the tons of hay produced by the acre-feet of water used. *The results of this trial showed that on medium soil slightly more hay could be produced by irrigating once a week than by irrigating once in two weeks, but the additional hay secured was not great enough to warrant the additional labor involved in irrigation and the additional water charge.* The hay production on the field irrigated once in three weeks was so low that it would not be economical farming to irrigate with this long an interval. The greatest return for the water used or in other words *the highest duty of water per acre-foot was secured when water was applied once in two weeks.*

LYSIMETER INVESTIGATIONS

The study of soil moisture in the rather light soil of the Umatilla Experiment Farm required the installation of eight lysimeters in order to trace more closely than was possible under field conditions the relation of the moisture to the soil and to crops. The lysimeters are concrete tanks 3.3 feet square and contain 6 feet depth of soil. The soils were taken from the field in six-inch layers and placed in the lysimeters in the same order and in as near the original density as possible. The soils are all irrigated with the same amounts of water, the water which percolates through the six feet of soil being collected through a funnel in the bottom of the tank and measured. The data on the amount of water applied and percolated, shown graphically in Fig. 11, are the average of six years results. The application figures are for the water applied by irrigation plus the rainfall. The five soil types used are fine, medium, and coarse sand, silt, and silt loam. Of the medium-sand lysimeters one has no crop, another soy beans in the summer and vetch in the winter, both crops being turned into the soil; another, alfalfa without manure; the fourth alfalfa with manure applied annually. The fine sand, coarse sand, silt, and silt loam soils grow alfalfa without fertilization.

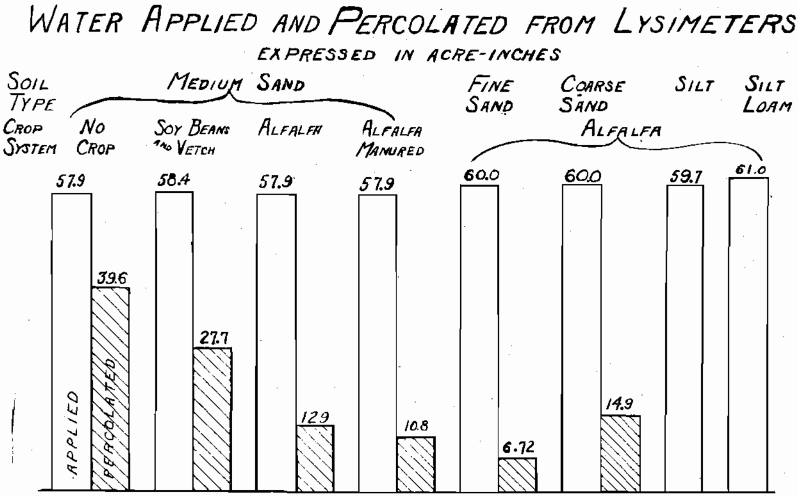


Fig. 11. The sandy soils all lost water by percolation, while the silt and silt loams held all the water applied. The percolation loss was less from the soil where alfalfa was grown than from the soil without crop or that with soy beans and vetch sequence. The manured alfalfa soil held more water than the soil growing alfalfa without manure.

The percolation from the medium sand has been greatest each year from soil not growing a crop, decreasing in the order mentioned for soils growing soy beans and vetch, alfalfa, and alfalfa manured. The percolation from the lysimeters growing alfalfa has been lowest from the fine sand, greater from the medium sand, and greatest from the coarse sand. The silt and silt loam soils have held all the water applied to them. The rate of percolation from the no-crop and from the soy bean-vetch lysimeters increases very rapidly, usually eight to ten hours after irrigation, reaching a maximum flow within an hour after the first increase. From the maximum rate of flow the flow gradually decreases until the next irrigation. The increased percolation after irrigation from the fine, medium, and coarse sand growing alfalfa comes 20 to 24 hours after irrigation and does not reach as high a rate as from the no-crop and vetch-soy bean lysimeter. *The results show that there is a tendency for the percolation to decrease as the soils are cropped continuously.*

RESULTS OF SOIL FERTILITY EXPERIMENTS

Arid soils are naturally low in organic matter because the moisture has not been sufficient to produce a large vegetative growth. The extremely low humus and nitrogen contents of virgin arid soils make the subject of soil fertility one of first importance. A number of experiments being conducted deal directly with the fertility of the soil as measured by their crop-producing power when treated with commercial fertilizers, barnyard manure, and green manure crops.

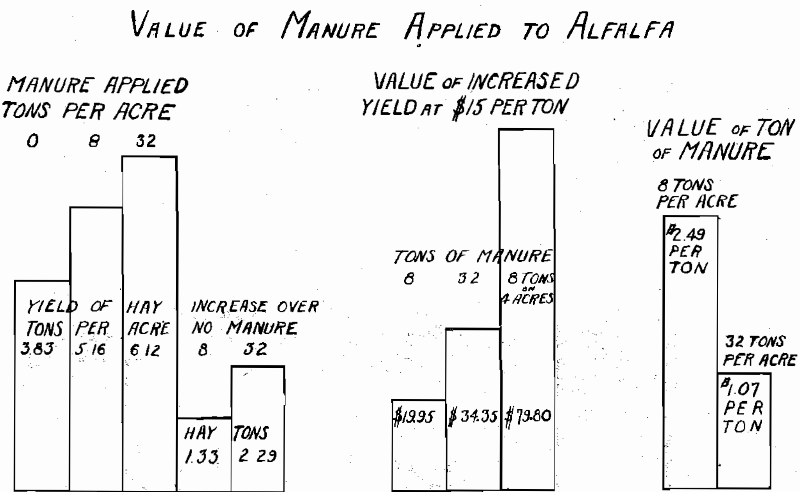


Fig. 12. The application of manure produces pronounced increases in the yield of alfalfa. The value of manure was found to be $2.49 per ton when applied 8 tons per acre and only $1.07 when applied at 32 tons.

ROTATION EXPERIMENTS

The crop rotations with green and stable manure have included alfalfa grown continuously; alfalfa for four years followed by corn one year; corn in the summer with a green manure crop of hairy vetch in the winter; and corn in the summer with a green manure crop of rye in the winter. Each of these crop systems has plots with no manure, with manure at eight and at thirty-two tons an acre applied annually.

The value of manure applied to alfalfa is shown in Fig. 12. The average production of alfalfa for four years on plots not having manure was 3.83 tons an acre; on plots having 8 tons of manure, 5.16 tons; and on plots having 32 tons of manure, 6.12 tons. The increased return from manure has been very pronounced. The plots having 8 tons of manure produced 1.33 tons more hay than the plots without manure, or a value of $19.95 with hay at $15 a ton. The plots having 32 tons of manure an acre produced a gain of 2.29 tons of hay valued at $34.35 more than the plots without manure. Had the 32 tons been spread over four acres at the rate of 8 tons an acre instead of over one acre, the increased yield would have been 5.32 tons valued at $79.80, or an increased return of $45.45 over that realized when the 32 tons were applied on one acre.

Still valuing hay at $15 a ton the manure applied at the rate of 8 tons, by increasing the yield, gave a return of $2.49 a ton, while that applied at the rate of 32 tons yielded only $1.07 a ton. These results show very definitely that *greater returns per ton of manure were secured from the 8-ton applications than from those of 32 tons. Since manure can be secured only in limited quantities it should be carefully applied.* The yield of corn has shown also that it is much more profitable to apply 8 tons of manure per acre than to apply 32 tons.

Corn following alfalfa plowed under has shown that very pronounced results may be secured by rotation. Where no manure was used corn following alfalfa yielded 3.09 tons of dried fodder per acre as compared with .68 ton where corn was grown continuously. On plots having 8 tons of manure an acre the yield following alfalfa was 3.94 tons of fodder as compared with 2.07 tons on the continuous corn plots. On plots having 32 tons of manure the yield was 4.58 tons of fodder following alfalfa and 3.57 tons following corn so that an increase of 1 ton of fodder per acre was secured from plowing under alfalfa even though 32 tons of manure had been applied.

Fig. 13. A successful irrigated mixed grass pasture on the Umatilla Project.

A rotation experiment to which commercial fertilizers and barnyard manure were applied has completed the second cycle. The rotation consisted of 2 years clover, 1 year corn, and 1 year potatoes. The fertilizers applied include the three essential fertilizers, nitrogen, potash, and phosphorus, applied singly and in combinations. The nitrogen plots have yielded slightly higher than the check plots without fertilization. The soil of the Experiment Station is rather high in potash and phosphorus, so these elements have not given sufficient increased yields to justify their use. When manure is used in addition to the commercial fertilizers there is a slight indication that the yield is higher than the yield of either the commercial fertilizer or the manure alone.

Sulfur, which has been widely used as a fertilizer for alfalfa during recent years, has not yet given increased yields on the Experiment Station. Two cooperative experiments conducted on silt soils have, however, given 20 percent increase in yields from the use of eighty pounds of sulfur per acre.

MIXED GRASS PASTURES

The place of mixed grass pastures in the agriculture of the light soils of the Columbia Basin will undoubtedly become more important as the farming practices become more stabilized with more livestock on the farms.

Returns equal to if not higher than those secured from hay land are frequently obtained from mixed grass pastures on the finer sandy soils. An area of grass pasture will produce approximately as much feed as the same area in alfalfa and has the advantage that there is no harvesting cost and the stock will do better on green pasture than on dry hay. Fig. 13 is an illustration of a successful grass pasture on the Umatilla Project. The pasture grasses are all shallow rooted and should not be planted on coarser soils where it is difficult to maintain uniform moisture conditions or where water is not frequently available. Seepage ground which is not water-logged is ideal for grass pastures, and pastures are the best means of utilizing such ground.

A pasture made up of a number of grasses has a much more uniform and higher carrying capacity than one with only one grass because the various grasses have different growing habits, and while one may be dormant another will be producing sufficient feed to carry the stock. The following grasses have been tried singly and in combination at the Umatilla Experiment Station. The mixture given below sown at the rate of 22 pounds an acre is recommended.

Orchard grass	6
Kentucky blue-grass	6
Meadow fescue	4
Smooth brome grass	4
Alsike clover	2
Total	22

If the ground is wet from seepage the meadow fescue should be replaced with red top at the same rate.

Irrigated pastures require careful management if the greatest returns are to be secured. The best results have been secured from fall seeding although early spring seedings are frequently successful.

The border method of irrigation is admirably adapted to use in pastures, since the light frequent applications which pastures require may be made with this system. During the first year a pasture needs irrigation once a week and if the maximum results are to be secured after the first year it should be irrigated at intervals of 10 days. Pastures should not ordinarily be used the first year in order that the stand may become thoroughly established, but if the plants have made a big growth the pasture may be used late the first year. A pasture should be harrowed lightly each year to keep weeds down and to spread the manure. Light applications of manure have been found to be valuable in increasing the carrying capacity. The carrying capacity of a pasture may be increased considerably if it is divided and the stock rotated between the parts.

APPENDIX

Tables giving the flow of water in ditches and pipe lines and over weirs and the time required for given applications of water.

TABLE I. CARRYING CAPACITY IN SECOND-FEET OF DIRT DITCHES

Bottom width 1.25 to 3 feet with side slope 1½ to 1 and with water 3 to 15 inches deep.

Width	Fall 1 foot per 1000 feet				
	Depth of water				
	3 inches	6 inches	9 inches	12 inches	15 inches
1.25	0.19	0.72	1.66	......	......
1.50	0.22	0.96	1.91	......	......
2.00	......	1.19	2.35	4.20	......
3.00	......	......	3.38	5.85	9.15
	Fall 0.5 foot per 1000 feet				
2.00	......	0.84	1.66	2.98	......
3.00	......	......	2.34	4.05	6.35

The body of the table gives the flow in second-feet in ditches with different grades and depths of water. Example: A stream 9 inches deep in a ditch 3.0 feet wide with a grade of 1 foot per 1000 feet delivers 3.38 cubic-feet per second.

TABLE II. CARRYING CAPACITY, IN CUBIC FEET PER SECOND, OF CONCRETE PIPES LAID IN SECTIONS 2 FEET LONG

Without correction for entrance or outlet losses.

Head in feet per 1000 ft. for friction	Carrying capacity, in second-feet when running full			
	8 inch	12 inch	16 inch	20 inch
0.5	0.23	0.71	1.58	2.92
0.6	0.25	0.78	1.72	3.20
0.7	0.27	0.84	1.86	3.46
0.8	0.29	0.90	1.99	3.69
0.9	0.30	0.95	2.11	3.91
1.0	0.32	1.00	2.22	4.12
1.5	0.39	1.23	2.72	4.92
2.0	0.46	1.42	3.14	5.83
3.0	0.56	1.74	3.86	7.15
4.0	0.65	2.01	4.45	8.25
5.0	0.73	2.25	4.97	9.22
6.0	0.80	2.47	5.45	10.11
7.0	0.86	2.66	5.89	10.91
8.0	0.92	2.84	6.29	11.66
9.0	0.97	3.02	6.67	12.38
10.0	1.03	3.18	7.04	13.05
12.0	1.12	3.48	7.70	14.30
14.0	1.22	3.76	8.33	15.43
16.0	1.30	4.02	8.90	16.50
18.0	1.38	4.27	9.44	17.52
20.0	1.45	4.48	9.92	18.40
25.0	1.62	5.03	11.13	20.65
30.0	1.78	5.51	12.20	22.60

The body of the table gives the flow in second-feet in pipe lines of varying sizes and grades.

Example: A 12-inch pipe line with 16 feet per 1000 fall when running full delivers 4.02 cubic feet per second.

TABLE III. DISCHARGE OF STANDARD CIPPOLETTI AND STANDARD SUPPRESSED RECTANGULAR WEIRS IN CUBIC FEET PER SECOND

Head depth in inches	Head, depth in feet	Width of weir, feet					
		1.0	1.5	2.0	2.5	3.0	4.0
	.20	.30	.45	.60	.75	.90	1.20
2½	.21	.32	.49	.65	.81	.97	1.30
	.22	.35	.52	.69	.87	1.04	1.39
2¾	.23	.37	.56	.74	.93	1.11	1.48
	.24	.40	.59	.79	.99	1.19	1.58
3	.25	.42	.63	.84	1.05	1.26	1.68
	.26	.45	.67	.89	1.11	1.34	1.78
3¼	.27	.47	.71	.94	1.18	1.42	1.89
	.28	.50	.75	1.00	1.25	1.50	1.99
3½	.29	.53	.79	1.05	1.32	1.58	2.10
	.30	.55	.83	1.11	1.39	1.66	2.21
3¾	.31	.58	.87	1.16	1.45	1.74	2.32
	.32	.61	.91	1.22	1.53	1.83	2.44
4	.33	.64	.96	1.28	1.60	1.91	2.56
	.34	.67	1.00	1.33	1.69	2.00	2.67
4¼	.35	.70	1.05	1.39	1.74	2.09	2.79
	.36	.73	1.09	1.45	1.82	2.18	2.91
4½	.37	.76	1.14	1.52	1.90	2.27	3.03
	.38	.79	1.18	1.58	1.98	2.37	3.15
	.39	.82	1.23	1.64	2.05	2.46	3.28
4¾	.40	.85	1.28	1.70	2.13	2.56	3.41
	.41	.88	1.33	1.77	2.21	2.65	3.53
5	.42	.92	1.37	1.83	2.29	2.75	3.66
	.43	.95	1.42	1.90	2.38	2.85	3.80
5¼	.44	.98	1.47	1.97	2.46	2.95	3.93
	.45	1.02	1.52	2.03	2.54	3.05	4.06
5½	.46	1.05	1.58	2.10	2.63	3.15	4.20
	.47	1.09	1.63	2.17	2.71	3.25	4.34
5¾	.48	1.12	1.68	2.24	2.80	3.36	4.48
	.49	1.16	1.73	2.31	2.89	3.46	4.62
6	.50	1.19	1.79	2.38	2.98	3.57	4.76
	.51	1.23	1.84	2.45	3.07	3.68	4.90
6¼	.52	1.26	1.89	2.52	3.16	3.79	5.05
	.53	1.30	1.95	2.60	3.25	3.90	5.20
6½	.54	1.34	2.00	2.67	3.34	4.01	5.34
	.55	1.37	2.06	2.75	3.44	4.12	5.49
6¾	.56	1.41	2.12	2.82	3.53	4.23	5.64
	.57	1.45	2.17	2.90	3.63	4.35	5.79
7	.58	1.49	2.23	2.97	3.72	4.46	5.95
	.59	1.53	2.29	3.05	3.82	4.58	6.10
7¼	.60	1.57	2.35	3.13	3.91	4.69	6.26
	.61	1.60	2.41	3.21	4.01	4.81	6.42
7½	.62	1.64	2.47	3.29	4.11	4.93	6.57
	.63	1.68	2.53	3.37	4.21	5.05	6.73
	.64	1.72	2.59	3.45	4.31	5.17	6.89
7¾	.65	1.76	2.65	3.53	4.41	5.29	7.06
	.66	1.81	2.71	3.61	4.52	5.42	7.22
8	.67	1.85	2.77	3.69	4.62	5.54	7.38
	.68	1.89	2.83	3.81	4.72	5.66	7.55
8¼	.69	1.93	2.89	3.89	4.83	5.79	7.72
	.70	1.97	2.95	3.98	4.93	5.92	7.89
8½	.71	2.01	3.02	4.06	5.04	6.04	8.06
	.72	....	3.08	4.15	5.14	6.17	8.23
8¾	.73	......	3.15	4.24	5.25	6.30	8.40
	.74	......	3.21	4.33	5.36	6.43	8.57
9	.75	......	3.28	4.41	5.47	6.56	8.75
	.76	......	......	4.51	5.58	6.69	8.92
9¼	.77	......	......	4.60	5.69	6.82	9.10
	.78	......	......	4.69	5.80	6.96	9.28
9½	.79	......	......	4.78	5.91	7.09	9.46
	.80	......	......	4.87	6.03	7.23	9.64
9¾	.81	......	......	4.96	6.14	7.36	9.82
	.82	......	......	5.05	6.25	7.50	10.00

The body of the table gives the flow in second-feet when given depths of water flow over weirs of various widths.

Example: A stream 0.54 foot deep over a weir 3 feet wide delivers 4.01 cubic feet per second.

TABLE IV. TIME PER ACRE IN HOURS REQUIRED FOR APPLICATIONS OF 3 TO 10 ACRE-INCHES.

Heads from 0.50 to 5.0 second-feet

Head in second feet	Depth of Application, acre-inches							
	3	4	5	6	7	8	9	10
.50	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
.75	4.00	5.30	6.60	8.00	9.30	10.60	12.00	13.30
1.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
1.25	2.40	3.20	4.00	4.80	5.60	6.40	7.20	8.00
1.50	2.00	2.70	3.30	4.00	4.60	5.30	6.00	6.70
1.75	1.70	2.30	2.80	3.40	4.00	4.60	5.10	5.70
2.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
2.25	1.30	1.80	2.20	2.70	3.10	3.55	4.00	4.40
2.50	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00
2.75	1.10	1.40	1.80	2.20	2.50	2.90	3.20	3.60
3.00	1.00	1.30	1.60	2.00	2.30	2.70	3.00	3.30
3.25	.92	1.20	1.50	1.80	2.15	2.45	2.70	3.00
3.50	.86	1.10	1.40	1.70	2.00	2.25	2.50	2.80
3.75	.80	1.05	1.30	1.60	1.80	2.10	2.40	2.60
4.00	.75	1.00	1.20	1.50	1.70	2.00	2.20	2.50
4.25	.70	.94	1.15	1.40	1.60	1.80	2.10	2.35
4.50	.66	.89	1.10	1.30	1.50	1.70	2.00	2.20
4.75	.63	.84	1.05	1.25	1.45	1.65	1.90	2.10
5.00	.60	.80	1.00	1.20	1.40	1.60	1.80	2.00

The body of the table gives the time in hours required for certain streams to deliver given depths of water on 1 acre.

Example: A head of 3.50 second-feet delivers a 4-inch application on 1 acre in 1.1 hours. To find the time required to irrigate an acre to a desired depth, locate the head in left-hand column corresponding to stream going onto the land and drop over horizontally until under the depth of application desired, where the number will be found representing time in hours required.