Irrigated Pastures

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I. Introduction

Irrigated pastures have provided feed for the livestock of the western United States since its settlement. The acreage has expanded to an estimated 2.7 million in the 17 western states, according to the 1940 Census of Irrigation. Twelve per cent of the irrigated land of the west was in pastures, 37 per cent in Nevada and nearly 25 per cent in Oregon. The California acreage was estimated at about 560,000 in 1949, most of which developed since 1930 and nearly half since 1946. Five acres planted in the Werribee District of Victoria, Australia in 1914, was the beginning of a development which reached approximately one-third million acres by 1947 according to Morgan (1949).

Factors which have contributed to a large irrigated pasture acreage are the development of new irrigated land, selection and use of species which are highly productive on a wide variety of soils, and the need for additional forages to supplement other sources, particularly rangeland. The low labor requirement for this kind of irrigation farming has appealed to many operators during recent years of scarce and costly labor.

Many of the Agricultural Experiment Stations of the West included studies on irrigated pastures in their earliest projects. Recent research has been directed both towards improvement of existing pastures and development of new pastures on various types of soils including some of the best.

The writers have placed greatest emphasis in this review on recent experimental data but the lack of information on numerous points has necessitated the use of some less well authenticated evidence.

II. Pasture Soils

The soils upon which irrigated pastures are grown vary widely in physical and chemical characteristics. In recent years some of the most fertile and productive soils in the West have been seeded to irrigated pastures. A large part of the acreage, however, is on soils not well suited for tillage because of poor drainage, excessive salts, shallowness, or the presence of stones, steep slopes and other conditions unfavorable to cultivation. The many species of grasses and legumes used in pastures show wide differences in soil adaptation and tolerance to adverse situations.

Characteristics of the soil which influence production and selection of species are fertility, texture, depth, drainage, and salinity and alkalinity. For a more thorough treatment of the management of irrigated soils, the reader is referred to Thorne and Peterson's (1949) book on this subject, and to the manual by Richards (1947) on the diagnosis and improvement of saline and alkaline soils. The present discussion is confined to the adaptation of species to particular soil conditions.

Much of the irrigated pasture acreage is on soils which are typical of arid conditions. Thorne (1948) characterizes these soils as being low in organic matter and containing adequate or excessive quantities of calcium, sodium, magnesium, potassium, carbonates and sulfates. He further indicates that these soils, when placed under irrigation, often contain insufficient phosphorus and nitrogen for maximum production. With irrigation and growing of crops, organic matter is increased, microbial activity stimulated, and many mineral constituents are brought into solution.

The irrigated land of the western United States is on valley bottoms and terraces which developed from material transported and deposited by water. Most of the streams emerged from mountain canyons to deposit sediment at floodtime in alluvial fans. Pastures are mostly on heavy textured soils laid down under slow moving water or lacustrine deposition. The latter soils are particularly heavy and may be quite high in organic matter. Some of the older depositions have developed profiles with heavy textured or cemented hardpan subsoils. Varying degrees of salt accumulations are found.

Soil texture and depth are important factors in species adaptation. Deep rooted plants such as alfalfa (*Medicago sativa*) are used on the deep, coarse to medium textured soils. Hamilton *et al.* (1945) point out that good pastures are not readily established and maintained on very sandy soils. The low water holding capacity of these soils and injury to ladino clover (*Trifolium repens latum*) stolons by trampling limit the use of this species. On fine textured soils, the shallow rooted species such as ladino clover are quite satisfactory. Ladino clover and narrowleaf birdsfoot trefoil (*Lotus corniculatus tenuifolius*) are two of the few species which produce satisfactorily on the extremely heavy adobe soils in central California. These same species are grown successfully on soils underlain with a claypan layer a few inches below the soil surface. This impervious subsoil increases the efficiency of water use by preventing downward percolation below the root zone.

Excessively wet soils in irrigated regions are caused by (1) direct application of water, (2) seepage from canals and ditches, and (3) subsurface flows from areas receiving excessive precipitation or irrigation, (Thorne and Peterson, 1949). Wet conditions arising from direct water application are generally localized and result from over-irrigating, improper leveling, failure to provide drainage, or to unsatisfactory balance between the head of water and the size of the check or basin. These conditions are normally avoidable and are discussed under later headings.

More extensive wet areas are found where drainage is difficult or not practical such as in large valley bottoms and along natural waterways which are subject to flooding or seepage. Because of wet conditions, and often the presence of salts, these areas are difficult to manage and productivity is low because the most productive species are not well adapted.

These valley bottoms or mountain meadows are used extensively for spring and fall grazing and the production of wild hay for wintering range cattle. Pittman and Bennett (1948) were able to double yields in the second and third year after alsike clover (*Trifolium hybridum*) and red clover (*Trifolium pratense*) were broadcast on undisturbed sod. An additional significant increase was obtained by plowing and seeding timothy (*Phleum pratense*) and redtop (*Agrostis alba*) or bromegrass (*Bromus *inermis*) and meadow fescue (*Festuca elatior*) with the clovers. The above treatment when combined with fertilization, frequent light irrigations and control of water to prevent prolonged flooding, resulted in nearly 4 times the yield of native sod.

Reed canarygrass (*Phalaris arundinacea*) in combination with strawberry clover (*Trifolium fragiferum*) produced excellent pasture on land too wet for alfalfa in unpublished studies conducted at the Utah Station. In preliminary trials at the California Station, Reed canarygrass, perennial ryegrass (*Lolium perenne*), tall fescue (*Festuca elatior arundinacea*), narrowleaf trefoil, and strawberry clover ranked in the order named in total production when grown under continuous flooding over a period of several months.

Research is being initiated by federal agencies in cooperation with several of the western states on the improvement of natural meadows. This is an important source of livestock feed and the problem of improvement warrants greater attention than it has received in the past.

According to Magistad and Christiansen (1944), "A large part of the 20,000,000 acres under irrigation in the 19 Western States contains enough soluble salt to depress crop yields. A much smaller area contains so much alkali that crop production is greatly curtailed and unprofitable. Thousands of acres have been abandoned because of salinity." In arid regions, salts accumulate chiefly because of irrigation and poor drainage (Richards, 1947). Since poorly drained soils are not easily tilled, they are used extensively for the production of forage. Thus, in irrigated regions the problem of saline and alkali soils is one of great importance in connection with forage production.

Richards (1947) has classified salted soils into saline, saline-alkali, and nonsaline-alkali soils. The saline soils are defined as soil "for which the conductivity of the saturation extract is greater than 4 millimhos per cm. (at 25°C.) and the exchangeable-sodium-percentage is less than 15. The pH of the saturated soil paste is usually less than 8.5." These soils are characterized by white crusts on the surface or by streaks of salt in the soil. They are reclaimed by leaching and drainage, after which they become normal soils. The saline-alkali soils are defined as "soils for which the conductivity of the saturation extract is greater than 4 millimhos per cm. (at 25°C.) and the exchangeable-sodium-percentage is greater than 15. The pH of the saturated soil paste may exceed 8.5." The nonsaline-alkali soils are those "for which the exchangeable-sodium-percentage is greater than 15 and the conductivity of the saturation extract is less than 4 millimhos per cm. (at 25°C.). The pH values for these soils generally range between 8.5 and 10." The latter two types of soil are more difficult to reclaim because of the low rate of water penetration.

Hamilton *et al.* (1945) point out that the roots of salt-tolerant forage plants increase the permeability of salty soils and speed up the rate at which salt may be leached from them. According to Richards (1947) alkaline soils require measures to improve the soil structure after suitable base exchange and leaching has removed harmful amounts of sodium. For this purpose they consider grass roots especially effective.

Bartels and Morgan (1944) consider the degree of reclamation of salty soil to be proportional to the amount of water applied. They found that when sufficient leaching had occurred to permit growth of barley

TABLE I

Salt Tolerance of Forage Crops According to Richards (1947). Tolerance Decreases from Top to Bottom in Each Division. Scientific Names have been Added

GOOD SALT TOLERANCE

Alkali sacaton (*Sporobolus airoides*)
Salt grass (*Distichlis spp.*)
Nuttal alkali grass (*Puccinellia nuttalliana*)
Bermuda grass (*Cynodon dactylon*)
Rhodes grass (*Chloris gayana*)

Rescue grass (*Bromus catharticus*)
Canada wild rye (*Elymus canadensis*)
Beardless wild rye (*Elymus triticoides*)
Western wheatgrass (*Agropyron smithii*)

MODERATE SALT TOLERANCE

White sweet clover (*Melilotus alba*)
Yellow sweet clover (*Melilotus Officinalis*)
Perennial ryegrass (*Lolium perenne*)
Mountain brome (*Bromus carinatus*)
Barley (hay) (*Hordeum vulgare*)

Birdsfoot trefoil (*Lotus corniculatus*)
Strawberry clover (*Trifolium fragiferum*)
Dallis grass (*Paspalum dilatatum*)
Sudan grass (*Sorghum vulgare sudanense*)
Hubam clover (*Melilotus alba annua*)
Alfalfa (California Common) (*Medicago sativa*)

MODERATE SALT TOLERANCE (*Continued*)

Tall fescue (*Festuca elatior arundinacea*)
Rye (hay) (*Secale cereale*)
Wheat (hay) (*Triticum aestivum*)
Oats (hay) (*Avena sativa*)
Orchardgrass (*Dactylis glomerata*)

Blue grama (*Bouteloua gracilis*)
Meadow fescue (*Festuca elatior*)
Reed canary (*Phalaris arundinacea*)
Big trefoil (*Lotus uliginosus*)
Smooth brome (*Bromus inermis*)

Tall (meadow) oat (*Arrhenatherum elatius*)
Cicer milk vetch (*Astragalus cicer*)
Sour clover (*Melilotus indica*)
Sickle milk vetch (*Astragalus falcatus*)

POOR SALT TOLERANCE

White (dutch) clover (*Trifolium repens*)
Meadow foxtail (*Alopecurus pratensis*)
Alsike clover (*Trifolium hybridum*)
Red clover (*Trifolium pratense*)
Ladino clover (*Trifolium repens latum*)
Burnet (*Sanguisorba minor*)

grass (*Hordeum maritimum*), the land would support wimmera ryegrass (*Lolium rigidum*). Morgan (1947) considers land leveling essential to reclamation of salty land. Leveling makes possible the uniform application of water, to leach salts downward. He reports that a field which had a salt concentration in 1939 of 0.84 to 1.01 per cent in the 6- to 60-inch zone was leveled, sown to pasture, and irrigated 12 to 19 times a year. By 1946 the salt was reduced to 0.10 to 0.25 per cent. Light irrigations were given the pasture, the annual average totaling approximately 2.5 acre feet. During the course of the study the productivity of the pasture steadily increased.

Many native species possess marked tolerance of salty soils, but they are almost without exception of relatively low forage value. Experience gained through the years has been sufficient to permit a rough classification of plants as to their salt tolerance. In recent years the work of the U.S. Regional Salinity Laboratory at Riverside, California has greatly expanded and refined our conception of the adaptation of plants to salty soils. The salt tolerance of a number of forage species, as reported by Richards (1947) is reproduced in Table I. The scientific names have been added to aid in identification. The growth made by wheat, oats or barley on salty land serves as a useful guide in choosing the best species for seeding the area to pasture.

The principal effect of salt on crop production is a reduction in growth of plants. Since the salts in the soil solution retard the movement of water into the plants, it should be kept as diluted as possible by frequent irrigation. The applications should be light if there is danger of raising the water table, but heavier applications may be made if adequate drainage has been provided. Magistad (1945) and Hayward and Wadleigh (1949) have presented reviews of plant growth relations on saline and alkali soils, and Hayward and Magistad (1946) state the problem and describe the work of the Laboratory at Riverside.

III. Choosing Productive Mixtures

Relatively few species are extensively used in irrigated pastures. These are listed together with some of their characteristics in Table II. Smooth bromegrass, reed canarygrass, and tall oatgrass (*Arrhenatherum elatius*) are used most widely in the cooler regions as contrasted to dallis grass (*Paspalum dilatatum*) and rhodesgrass (*Chloris gayana*) which are confined to the hot southern regions and areas of mild winter temperatures. Similarly, bur clover (*Medicago hispida*), a winter annual is used only in areas with mild winters. Italian ryegrass (*Lolium multiflorum*) and perennial ryegrass are most widely used in the Pacific Coast states.

TABLE II

The Major Irrigated Pasture Species, Some of their Characteristics, and the Conditions under which they are Likely to be of Greatest Value

Species	Growth habit	Palata-bility	Length of life	Probable best use [a]	
				Land	Water
Tall Oat (*Arrhenatherum elatius*)	Bunch	High	Short perennial	Arable	Moderate
Smooth Brome (*Bromus inermis*)	Rhizomatous	High	Perennial	Arable	Limited
Rhodesgrass (*Chloris gayana*)	Stoloniferous	Moderate	Perennial	Salty	Moderate
Orchard (*Dactylis glomerata*)	Bunch	Moderate	Perennial	Arable	Abundant
Tall Fescue (*Festuca elatior arundinacea*)	Bunch	Low	Perennial	Salty	Moderate
Italian Ryegrass (*Lolium multiflorum*)	Bunch	High	Annual	Arable	Moderate
Perennial Ryegrass (*Lolium perenne*)	Bunch	High	Short perennial	Arable	Moderate
Dallis Grass (*Paspalum dilatatum*)	Bunch	Moderate	Perennial	Arable	Abundant
Reed Canary (*Phalaris arundinacea*)	Rhizomatous	Moderate	Perennial	Wet	Excess
Narrowleaf Birdsfoot Trefoil (*Lotus corniculatus tenuifolius*)	Creeping	High	Perennial	Salty	Moderate
Broadleaf Birdsfoot Trefoil (*Lotus corniculatus arvensis*)	Nonspreading	High	Perennial	Arable	Moderate
Bur Clover (*Medicago hispida*)	Nonspreading	High	Annual	Arable	Moderate
Alfalfa (*Medicago sativa*)	Nonspreading	Moderate	Perennial	Arable	Limited
Sweet Clover (*Melilotus spp.*)	Nonspreading	Low	Biennial	Wet or salty	Limited
Strawberry Clover (*Trifolium fragiferum*)	Stoloniferous	High	Perennial	Wet and salty	Excess
Red Clover (*Trifolium pratense*)	Nonspreading	Moderate	Short perennial	Wet arable	Abundant
Ladino Clover (*Trifolium repens latum*)	Stoloniferous	High	Perennial	Arable	Abundant

[a] Some species are of much wider usefulness than here implied, but are relatively superior under conditions indicated.

Narrowleaf trefoil is used extensively in Oregon and California. Broadleaf trefoil (*Lotus corniculatus arvensis*) is coming into some use at higher elevations where winter temperatures exclude the narrowleaf trefoil. Strawberry clover has as yet achieved little importance except on wet lands in widely scattered areas. The remaining species listed in the table, show a wide range of adaptation throughout the western states.

Many writers have pointed out that if several species are used in a mixture, the grazing animal has a more varied diet, stands may be improved, and higher and more uniform yields are obtained. Reasons given for using a number of species in a mixture are differences in seasonal growth habits, depth of rooting, and soil nutrient requirements. Studies at the Utah Experiment Station have at least partially supported these statements but data are also available showing that simple combinations may be highly productive.

Pasture mixture studies are difficult to conduct because of the large number of possible combinations which can be compared. Only 3 grasses and 3 legumes give rise to 49 different mixtures containing one or more grasses with one or more legumes. Eight grasses and 8 legumes provide 64 mixtures of a single grass with a single legume, 784 mixtures of 2 grasses with 2 legumes, 3,136 mixtures of 3 grasses with 3 legumes and 4,900 mixtures of 4 grasses with 4 legumes. There are a possible 65,025 different mixtures, using 1 to 8 grasses with 1 to 8 legumes, not including differences in seeding rates. Most pasture mixture studies have included selected species put in combinations considered of most value by the experimenter.

Some early studies brought forth excellent recommendations although they were not always carried over into agricultural practice. Sanborn (1894) rated tall oatgrass, timothy and alfalfa in the order named, and pointed out that Kentucky bluegrass (*Poa pratensis*) was relatively unproductive as a pasture grass. French (1902) recommended 4 mixtures for pasture, none of which contained Kentucky bluegrass although he stated that it, and some other species, might be added. He pointed out that a simple mixture of 10 pounds orchardgrass (*Dactylis glomerata*) and 6 lbs. red clover per acre was good for hay or pasture. He recognized the difference between meadow fescue and tall meadow fescue, characterizing the latter as a coarser, less desirable species. Welch (1914) recommended a mixture of Kentucky bluegrass 8, orchardgrass 5, smooth bromegrass 5, meadow fescue 4, timothy 4, and white clover (*Trifolium repens*) 2 lbs. per acre. It was a modification of a mixture he had grown for 4 years with excellent results. Later, Welch (1917) pointed out that orchardgrass and bromegrass were the more important components, while Kentucky bluegrass, meadow fescue and timothy were of lesser importance. Hansen (1924) reported on a study of 3 mixtures, all quite similar except that one lacked legumes. On the basis of both hay yields and grazing tests on these 3 mixtures he proposed a fourth, which became widely known as the Huntley mixture. It is much like Welch's (1914) mixture, differing only in seeding rate, the omission of timothy and the inclusion of alsike clover. In a slightly modified form the Huntley mixture became widely used in Utah and some adjacent areas under the name of Standard mixture No. 1.

Current recommendations of most experiment stations in western United States omit Kentucky bluegrass from pasture mixtures. Common white clover has been largely replaced by ladino clover. Several experiment stations include tall fescue in nearly all mixtures (Jones and Brown, 1949; Klages *et al.,* 1948; Rampton, 1945). Tall oatgrass is recommended as a component of mixtures by Law *et al.* (1945) and Keller *et al.* (1947b).

Pasture mixtures for well-drained irrigated land have received increased attention in Utah since 1943. Reports by Keller *et al.* (1945, 1947a, 1947b) and by Bateman *et al.* (1949) have shown that the modified Huntley mixture is a relatively low producer when utilized by dairy cattle under rotation grazing. These studies have shown that high producing mixtures were those dominated by smooth bromegrass, orchardgrass, tall oatgrass, tall fescue or reed canarygrass, or combinations of these, with 50 to 60 per cent alfalfa, red clover or ladino clover. In contrast, mixtures dominated by Kentucky bluegrass, meadow fescue, meadow foxtail (*Alopecurus pratensis*), or perennial ryegrass, with strawberry clover, alsike clover or any of several sources of ordinary white clover, would be much less productive.

Because of the low palatability of tall fescue in these studies, and the difficulty of obtaining good stands of reed canarygrass, these species are not recommended in Utah for well-drained irrigated land. The mixture currently recommended (Department of Agronomy, 1949) is based on 6 years' study of 36 mixtures and 3 years' study of 32 mixtures. It includes bromegrass 4, tall oatgrass 4, orchardgrass 3, wilt resistant alfalfa 3, red clover 3, and ladino clover 2 lbs per acre. In this mixture tall oatgrass and red clover reach high production quickest, following seeding. Bromegrass, orchardgrass, wilt resistant alfalfa and ladino clover are the more permanent components of the mixture. They have remained productive through 6 grazing seasons.

Many problems surrounding pasture mixtures need further investigation. Tall fescue is widely used in California, Oregon and other states. However, Cunningham (1948) reports tall fescue is poisonous to cattle in New Zealand. There have been no reports of poisoning from areas where tall fescue has been extensively used in the United States.

Almost no research has been carried out on seeding rates. A wealth of experience indicates that under favorable conditions for both germination and establishment, 50 to 60 per cent legumes will result if the legumes comprise one-fourth to one-third of the total weight of the seed. Size and viability of seed and vigor of seedlings may considerably modify these proportions. Excellent stands of ladino clover have been obtained with one-half lb. of seed, although 1 or 2 lbs. are more commonly recommended per acre. Mixture totals vary with the species used, but usually range between 10 and 20 lbs. per acre.

IV. Establishing Pastures

1. Preparation of Land for Irrigation

The method used for irrigating pastures is determined by topography, soil and subsoil texture and the amount of water available (Hamilton *et al.,* 1945; Jones and Brown, 1949) and in different regions is strongly influenced by local custom (Stewart, 1945). Although numerous types of irrigation systems are used, all may be grouped into either sprinkling or flooding methods. Land leveling is required for most flooding systems.

The strip check or border method of flood irrigation is widely used on relatively flat areas (Hamilton *et al.,* 1945; Bartels and Morgan, 1944; Rayner, 1941; Jones and Brown, 1949). Land is graded to provide 0.2 to 0.5 foot fall per 100 feet, although steeper slopes are used in some areas on soils which resist erosion. On land which has considerable side fall, the width of the checks should be adjusted to keep elevation differences between adjoining checks to 0.2 foot. Levees which guide the water moving across the field are about 2 feet wide at the base and have a settled height of about 6 inches. They are spaced at regular intervals but these may vary in width from field to field.

Factors which influence width of levee spacing are soil texture, slope, length of strips and rate of water delivery to each. The relationship which exists between availability of water and the size of strip checks for clay loam and clay soils is shown in Table III. For porous loam or sandy-loam soils, the delivery rates should be increased from 2 to 5 times those indicated in the table or the size of checks correspondingly decreased. Levees are often discontinued a few feet from the lower end of the field and the excess water is carried away by a drainage ditch. This avoids ponding of water and retards the encroachment of water tolerant species. Advantages of the strip check method of irrigation are low-labor requirements for irrigation and reasonably good control of water application. The cost of land preparation for irrigation may be large because of the leveling which is required.

The contour check method is used on heavy soils where the land is nearly flat or gently sloping. Levees are constructed on the contour to form irregular shaped basins of varying sizes. The vertical interval between levees is usually 0.2 foot, or less on very level land. Jones and Brown (1949) recommend that contour levees have a base width of 30 to 36 inches and a settled height of at least 12 inches. Fields are irrigated from basis to basin starting at the upper side of the field. Drainage following irrigation is improved by construction of a broad shallow ditch from the upper to the lower levee near the center of the basin. The ditch also serves to carry water for irrigating each next lower basin in the pasture.

TABLE III

Size of Strip Checks for Clay Loam and Clay Soils at Various Rates of Water Delivery to each Strip [a]

Flow delivered to each strip cu. ft. sec.	Length of check for various widths of strip			
	10 ft. wide	15 ft. wide	20 ft. wide	25 ft. wide
0.2	440	—	—	—
0.3	660	440	—	—
0.4	880	660	440	—
0.5	880	660	—	440
0.6	1320	880	660	—
0.7	1320	880	660	—
0.8	—	1320	880	660
0.9	—	1320	880	660
1.0	—	—	1320	880

[a] Jones and Brown (1949).

Little land moving is required for contour check irrigation other than to fill small depressions and remove high points with a land plane. Therefore, the initial preparation costs are much less than for the strip check method. Labor requirements are low although large heads of water are required and it is difficult to control the amount applied. Some modifications of this method are being tried in an effort to avoid difficulties resulting from slow or improper drainage.

Wild flooding is used for irrigating pastures in the Sierra Nevada foothills and throughout much of the Intermountain Region. Irrigation ditches are built on grades of 1½ to 2 inches per 100 feet and spaced at intervals of 50 to 300 feet depending upon the steepness of the slope. Water is distributed from the ditches at frequent intervals by raising the level with a dam at the downstream edge of the section to be irrigated. Little or no land preparation is required other than the construction of irrigation ditches. The initial cost is therefore very low, but constant attention and considerable skill is required by the irrigator if he is to make efficient use of his water. Thus the cost of labor for irrigation is large compared to other methods.

Little or no land preparation is required for sprinkler irrigation. A sprinkler system may have an advantage on shallow soils, and especially those underlaid with hardpan because the removal of surface soil may be very detrimental. Veihmeyer (1948) states that other advantages of sprinkling include effective use of a small flow of irrigation water, uniform distribution, and ease of adjusting water needs of different soils in the same field. He lists disadvantages of sprinklers as their high cost, more water lost by evaporation, and slow penetration of water on some soils which results in runoff before an adequate amount is applied. Various types of sprinklers are discussed in the abovementioned publication.

2. Seedbed Preparation and Seeding

Methods used in the preparation of a seedbed for irrigated pastures are similar to those used for all small seeded species. Hamilton *et al.* (1945) list the requirements of a good seedbed as fine textured, firm, moist, fertile, and free of weeds. Tillage operations to accomplish the desired results usually involve plowing or disking, harrowing, and packing except when seeding in pea or grain stubble. A springtooth harrow is sometimes used in place of the plow or disk on land relatively free of weeds.

Jones and Brown (1949) in California recommend an irrigation before seeding to settle the fills, firm the soil, and provide subsoil moisture. The field is then planed if irregular settling has occurred, and harrowed just before seeding. Nitrogen fertilizers, if used, are applied just before or at seeding time. Manure and phosphate fertilizers are normally worked into the soil during the seedbed preparation. Irrigation before seeding is seldom necessary in the Intermountain Region.

Pastures can be seeded at any time that favorable moisture conditions and temperature can be maintained. In areas having cold winters, 6 to 10 weeks of growing weather are required for the young plants to become winter hardy. Hamilton *et al.* (1945) point out that cool-season grass seedlings attain winter hardiness at an earlier age than the associated legumes. In the Intermountain Region of the Western United States it has been customary to seed pastures in the spring, on fall plowed land. However, an increasing number of farmers are seeding in

August in grain stubble or on land from which canning peas have been harvested. Post and Tretsven (1939) and Hamilton *et al.* (1945) recommend fall seeding if the land is not weedy, the grain has not shattered, and adequate irrigation water can be applied. Bingham and Monson (1946) consider grasshopper injury is avoided by late summer seeding in grain stubble.

In areas having mild winters, Jones and Brown (1949) recommend fall and early winter seeding. Matlock (1943) recommends seeding in August and September for various sites in Arizona. Robertson *et al.* (1948) recommend spring seeding but state that at high elevations where snow cover is dependable in winter, good success has resulted from late fall planting, germination occurring in early spring. This practice takes full advantage of spring precipitation, and saves some irrigation water and the labor of applying it. In California, the seeding time is adjusted to take advantage of the natural winter rainfall. It is seldom possible to establish a stand in dry weather by flood irrigation. However, a few farmers have established successful stands of ladino clover in the Sacramento Valley by airplane seeding in standing water. Ladino clover germinates rapidly in water and the seedlings are established by the time the field dries.

Drilling the seed is preferred if the seedbed is firm, but broadcasting is satisfactory on loose soil. Double seeding in different directions insures good broadcast distribution. Robertson *et al.* (1948) also recommend double seeding in drilling. Companion crops, if used, are seeded first. When planting a pasture in grain stubble the seed should be drilled, otherwise it is not easily covered.

Airplane seeding of pastures is becoming increasingly important in California on fields which are large enough to justify this method. From 300 to 500 acres can be seeded in a day at a cost of $1.00 to $2.00 per acre for double seeding. This method costs slightly more than ground broadcasting, but has the advantages of speed and the ability to seed when the field is too wet for ground equipment. Winter seedings in California are normally broadcast without covering.

Depth of seeding can be rather accurately controlled on a firm seedbed, but may be improved by the use of depth regulators on the drill. Shallow seeding of not more than one-half inch is normally recommended. Deeper seeding may be advisable on sandy soils or under conditions where adequate surface moisture is uncertain. The legume fraction of the mixture is usually seeded through the alfalfa hopper and the grass fraction through the grain side of a drill. Southworth (1949) has recently reported the use of rice hulls to improve the mechanical seeding qualities of chaffy grass seeds. A drill set to seed 160 lbs. barley per acre will seed an acre of pasture grasses and legumes mixed with 2 bushels (16 lbs.) rice hulls. Many grasses which are otherwise impossible to put through a drill, can be processed in a hammermill to remove awns and appendages. Instructions on seed processing and some effects of processing on germination of tall oatgrass are reported by Schwendiman *et al.* (1940) and Schwendiman and Mullen (1944).

The cultipacker-type seeder developed at the Wisconsin College of Agriculture and reported by Ahlgren and Graber (1940) and Ahlgren (1945) is ideal for seeding pastures. It covers the seed lightly, and firms the seedbed.

Irrigated pasture seedings are made either with or without companion crops. Companion crops are almost never used in California. Hamilton *et al.* (1945), Klages *et al.* (1948), and Davies and Christian (1945) consider a companion crop desirable to prevent wind damage. Bracken and Evans (1943) regard a companion crop as useful in helping to establish pastures on land that crusts easily. Companion crops have been used successfully in the establishment of experimental pastures in Utah by Keller *et al.* (1945, 1947b). Bateman (unpublished) at the Utah Station has successfully established both pastures and alfalfa while producing high yields of barley. He considers a companion crop worthwhile if in the Intermountain region proper management practices can be followed during its growth. Barley is an ideal companion crop when seeded at not over 50 to 60 lbs. per acre. Further information on companion crops is found under IV-3.

3. Management of the New Stand

New stands should be managed to promote rapid development of the seedlings. Prolonged close grazing or grazing when wet are conditions to be avoided. The stand should have a good top growth before winter temperatures cause growth to cease. Frequent light irrigations may be required until the roots become well developed. Davies and Christian (1945) in Australia, and Levy (1945) in New Zealand report satisfactory establishment of pastures under periodic heavy grazing during the seeding year, whether with or without a companion crop. Stands are grazed when the plants are 6 to 9 inches in height, usually at 8 to 12 weeks after planting. This grazing is repeated whenever the plants have made a 6 to 9 inch regrowth. Bartels (1947) points out that heavy grazing of young pastures is sometimes necessary to prevent perennial ryegrass from smothering out slower growing white clover.

Careful irrigation is required when a companion crop is seeded with the pasture. In a study conducted at the Utah Station it was found more profitable to harvest the companion crop for grain than to graze it. In an unpublished report, Bateman showed an advantage of 1,424 lbs. total digestible nutrients (T.D.N.) per acre plus 3,644 lbs. of straw for this method compared to grazing. During the seeding year (1946) the companion crop harvested for grain yielded 2,952 lbs. T.D.N. plus 3,644 lbs. straw per acre, while the grazed companion crop yielded 1,078 lbs. T.D.N. per acre, or a difference of 1,874 lbs. T.D.N. plus the straw. In the following year (1947) plots periodically grazed in 1946 yielded 450 lbs. more T.D.N. per acre than those taken through to grain. In 1948 and later, yields from the 2 treatments have not differed. Excellent stands were obtained under both treatments. The study was part of a pasture experiment containing 32 different mixtures (Keller *et al.*, 1947b). Bateman *et al.* (1949) point out that in 1947 this pasture yielded 5,342 lbs. T.D.N. per acre, or the equivalent of 5.31 tons alfalfa hay.

V. Management of Pastures

1. Grazing Management

The objectives of grazing management are (1) to maintain the desired balance between species, (2) to obtain continuous high production, and (3) to obtain utilization of the forage when it is most nutritious. Some forage species will tolerate close or continuous grazing while others will not. Most of the pasture mixtures now being recommended because of their high production of nutritious forage consist of species that require periods for regrowth, provided by rotation grazing, and will not survive if continuously closely grazed. With rotation grazing, two and preferably three or more pastures are grazed in rotation. After grazing, each pasture is irrigated and allowed to recover. The animals return to the first pasture from 3 to 6 or 8 times in one season. The system is highly flexible, and can be adjusted to fit into the other operations and requirements of each farm. Important considerations in developing a rotation grazing system are the number of subdivisions in the pasture, the number of days grazing in each, and the interval between grazings. Maximum yield of milk or beef will result only when the proper regrowth interval is used. If the interval is too short (the herbage too young) vigor of the plants will decline, and the grazing animals will expend an unduly large amount of energy in grazing. If the interval is too long the herbage will have lost palatability, and probably nitrogen also, and the grazing animals will not clean it up eagerly. Likewise, if the grazing period is too long in each subdivision the least desirable components of the pasture will be left until last. California dairymen have observed fluctuation in milk flow when the grazing period was as short as 5 days.

Rotation grazing was advocated many years ago by Harris (1913) and Welch (1914, 1917) and is widely used for irrigated pastures (Hamilton *et al.*, 1945; Starke, 1947; Bartels, 1944a; Semple and Hein, 1944), even though there are no experimental data under irrigation to indicate its value. The work of Hodgson *et al.* (1934) reporting a gain of 8.82 per cent from rotation over continuous grazing, has been referred to by Hamilton *et al.* (1945) and by Bracken and Evans (1943). According to Semple *et al.* (1934) rotation grazing increased production 10 per cent at Beltsville, Md., while studies in Missouri, Virginia, and South Dakota have given like results. Apparently these studies were conducted on pastures containing species that are tolerant of close grazing. Levy (1949) reports that close continuous grazing reduces production of New Zealand pastures by 50 per cent, and permits entry of weeds and undesirable grasses.

When a pasture is rather heavily stocked for a short period, the forage can be consumed when it is most nutritious, and fuller utilization and less selective grazing results. 't Hart (1949) reports that in Holland dairy cows grazing continuously achieved a utilization of 50 to 75 per cent of the forage. If the grazing period was reduced to 5 to 10 days, utilization was increased to 60 to 80 per cent but by reducing the grazing period to 1 to 2 days utilization was increased an additional 10 to 20 per cent. These data suggest a trend toward heavier stocking rates, for shorter periods under rotation grazing. The advantage of many subdivisions in a pasture, with short grazing periods is strikingly illustrated by data from the Blaettler Dairy in Santa Clara County, California, reported by Assistant Farm Advisor M. S. Beckley. In 1948 a 52-acre pasture was used in 3 subdivisions and grazed by 92 cows. Grazing 10 days in each subdivision they obtained forage with a feed replacement value of 2.5 tons alfalfa hay per acre. In 1949 the 52 acres was divided into 30 subdivisions that were grazed one day each by 110 cows. In 1948, milk production was uniformly maintained only 4 days out of the 10-day grazing period in each subdivision, with an average loss of 3 cans of milk per day for the last 6 days of each grazing period. In 1949 continuous high production was maintained. Feed replacement in 1949 was 5.5 tons alfalfa hay per acre.

Investigations at Werribee (Australia, 1947) have shown that sheep made similar gains when on rotations of 10 to 30 days. The more frequent grazings of a field did not alter the grass-legume ratio, but at 10-day intervals orchardgrass thinned out. Bartels (1944a) found that a 3-weeks' rest period between grazings enabled all seeded species to remain in the mixture; this is in agreement with observations in Utah.

In South Africa, Starke (1947) lists the following 5 reasons for rotation grazing of sheep: (1) less selective grazing, (2) less fouling of the forage, (3) more regular irrigation, (4) less internal parasite infection, and (5) better quality and more palatable forage. He used pastures of approximately 4.25 acres for 150 to 200 sheep.

According to Hamilton *et al.* (1945) and Klages *et al.* (1948), a pasture is considered ready to graze when about 6 inches of growth has occurred if tall species are used, and when 3 to 4 inches high if low-growing species predominate. Schoth (1944) considers ladino clover ready to graze at 3 to 4 inches, but recommendations of California investigators include not grazing ladino clover closer than 3 to 4 inches in order to permit rapid recovery.

It is generally considered good grazing management to allow the pasture to go into the winter with at least 3 to 4 inches growth. Schoth (1944) stresses the importance of avoiding close fall grazing of ladino clover, and points out that the fleshy stolons are damaged if ladino is pastured when the ground is frozen or wet.

Selective grazing cannot be avoided entirely, but it will be reduced to a minimum under rotation grazing if the various species in the mixture are of approximately equal palatability. Mowing the pasture occasionally, with the cutter bar raised to about 3 inches, does much to keep the pasture fresh and the forage palatable. Bartels (1944a) found clipping especially worthwhile if the pasture contained orchardgrass or *Paspalum*.

Continuous close grazing is still common in the Intermountain Region of the United States. Under intensive use, it leads in a few years to pastures consisting of Kentucky bluegrass and white clover. In experimental plots Keller *et al.* (1947a) and Bateman *et al.* (1949) found this combination a consistently low producer. The clover will be reduced or even eliminated, with further reduction in yield, if use is heavy, fertility low, and irrigation applications erratic.

2. Prevention of Bloat

The prevention of bloat has been a major problem in the management of irrigated pastures in some areas. Although surveys show the actual percentage loss from bloat to be small, individual stockmen have had catastrophic losses (Cole *et al.*, 1945). Practical experience has shown that there is little likelihood of bloat on pastures containing 40 to 50 per cent or more grass. It is difficult, however, to maintain a proper proportion of grasses and legumes at all seasons. The percentage of legumes in pasture can be reduced by applying nitrogen fertilizer or barnyard manure and withholding phosphate fertilizer (Klages *et al.*, 1948).

Another practical solution suggested by Cole *et al.* (1945) is to pasture legumes only after they reach the early bloom stage although these workers admit that no well-controlled experiments have been conducted relating to this factor. Bartels (1944a) supports this idea in suggesting 3 weeks for recovery in rotation grazing which gives the forage enough maturity to reduce bloat. This procedure may be expected to be more effective in pasturing a legume like alfalfa than with ladino clover which has an indeterminant habit of growth and low fiber content. Schoth (1944) recommends continuous grazing except for animals that bloat easily, which should be removed. Cole *et al.* (1945), however, discount the value of continuous day and night pasture and grain feeding as a means of preventing bloat. The feeding of minerals and the pasturing of legumes only when free of dew or rain also appear to lack supporting evidence.

The feeding of dry hay or straw before pasturing legumes is advocated by Robertson *et al.* (1948). This method was tested experimentally by Cole *et al.* (1943) who found that overnight feeding of alfalfa hay did not always prevent bloat although coarse-stemmed hay was more effective than fine stemmed hay. Cole and Kleiber (1945) found overnight feeding of 17 lbs. of sudan hay (*Sorghum vulgare Sudanense*) completely effective, while 4 to 7 lbs. fed 2 hours preceding pasturing was ineffective in preventing bloat. Mead *et al.* (1944) found that 5 lbs. of barley straw was not sufficient to prevent bloat.

Overnight pasturing of sudan was effective in preventing bloat on alfalfa the following day in studies by Cole *et al.* (1943). Advantages of sudan pasture suggested by these authors were high palatability and a growth habit permitting rapid ingestion. It might also have been added that this procedure is less costly than hay feeding. Starke (1947) states that dry sheep and pregnant ewes are less likely than lactating ewes to bloat on alfalfa.

According to Professor Glen Staten (unpublished data) alfalfa-grass mixtures are less productive in Southern New Mexico than alfalfa alone, while over a considerable area water economy prohibits use of ladino clover. Here, pasturing alfalfa is very common. Danger from bloat is somewhat reduced by grazing only relatively mature plants, but this results in considerable waste from trampling and fouling of the forage. Staten reports that some large operators are now obtaining full forage utilization, and have eliminated bloat, by harvesting each day's requirements and feeding as green chopped material.

Birdsfoot trefoil apparently does not cause bloat in either cattle or sheep. For this reason, some farmers are using this legume in preference to ladino clover or alfalfa.

3. *Irrigation*

For rapid growth and high production the soil occupied by the roots of pasture plants should have readily available moisture at all times. Depth of rooting determines the volume of soil available for supplying water to the plant. Although pasture plants vary in depth of rooting, the depth of soil is often the principal factor limiting root penetration.

The capacity of different soils to hold water varies greatly. The amount of readily available water (field capacity to permanent wilting percentage) held by a group of California soils ranged from 0.67 to 2.66 inches per foot depth of soil. This range, which is approximately 4-fold, emphasizes one of the reasons for the wide differences in amount and frequency of irrigation required.

Kramer (1949) discusses factors affecting the absorption of water and points out that poor aeration may cause a considerable reduction in absorption of water by plants and that the accumulation of carbon dioxide may be a more important factor in reduced water absorption than lack of oxygen. Poorly aerated conditions are common on many of the heavy clay soils used for irrigated pastures.

The total amount of irrigation water used during the year will depend upon the length of the growing season, natural rainfall, temperature, frequency and depth of wetting, and the species involved. Frequent light irrigation increases the percentage loss from evaporation. Too heavy irrigation on permeable soils will cause water to penetrate below the root zone and be lost. However, uniformity of penetration is difficult to attain.

Water used by transpiration and evaporation of 3 pasture crops under the climatic conditions at Davis, California are shown in Table IV. In 1943, Sullivan and Winright obtained records of acre-inches of water used per acre on 7 farm pastures in the Imperial Valley which indicated a range from 48 to 81 acre-inches with an average of 68.2 inches. Similar studies in San Bernardino County, also in Southern California, by Shultis and Campbell in 1943 showed a range from 36 to 80 acre-inches per acre, the average being 65. Jones and Brown (1949) state that 33 to 36 acre-inches of water were used on shallow clay loam soils applied in 12 irrigations over a 6-months' period in the Sierra foothills of Nevada County in Northern California. Robertson *et al.* (1948) recommend 2 to 4 acre-inches of water per irrigation at 10- to 14-day intervals during June through September for most areas of Colorado. Total water requirements for the season were 2½ to 3 acre feet.

The frequency of irrigation required depends upon how soon after irrigation the soil moisture within the root zone will again be reduced

TABLE IV

Water Used (Acre-Inches per Acre by Months) by Transpiration and Evaporation of Three Pasture Crops Grown at Davis, California [a]

Crop	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Alfalfa	1.5	3.9	5.3	6.5	8.0	6.6	5.0	2.0	1.2	40.0
Ladino clover	1.8	4.5	6.0	7.5	9.0	7.5	5.5	2.2	—	44.0
Sudangrass	—	—	2.0	3.2	4.0	3.4	2.2	1.2	—	17.0

[a] Data from Irrigation Division, California Agricultural Experiment Station.

to the permanent wilting percentage. The water holding capacity of the soil, temperature, and the crop influence the rate of water extraction. Many of the pastures in the interior valleys of California which contain ladino clover are irrigated at approximately 10-day intervals. On soils which are porous, irrigation may be required as frequently as every 7 days during the heat of summer. Pastures composed primarily of deeper rooted species, such as alfalfa and birdsfoot trefoil are irrigated at 2- to 4-week intervals depending upon the soil and temperature conditions.

Bartels *et al.* (1932) carried out extensive studies on frequency and amounts of irrigation water required for pastures in Victoria, Australia. The soil was described as a shallow clay loam which was slow to absorb water. Production of the pasture under prevailing conditions was best when 24 inches were applied in 6 irrigations of 4 inches each. Equal total amounts applied in either 4 or 8 irrigations were inferior.

The rate at which water is applied during irrigation has much influence on penetration. Doneen (1948) has pointed out that 50 per cent or more of the total water applied may be lost through deep percolation. Loss is greatest when the head of water is insufficient to reach the end of the check in a relatively short time. Deep percolation takes place near the head ditch. He suggests a large head be used to force the water through to the end of the check after which the head may be reduced to maintain an even flow to wet the length of the check until the desired depth of penetration has been reached.

The relationship of water delivery rate to size of the check is shown in Table III. The large delivery rates are desirable for the contour check method of irrigation because individual basins may contain up to 4½ or 5 acres (Jones and Brown, 1949). These require rapid flooding to obtain uniform penetration.

Sprinkling systems often can be advantageously used where only a small head of water is available. Frequent, light irrigations are also possible on porous soils which normally would require rather large amounts of water if flood irrigated. Veihmeyer (1948) has pointed out that while sprinkling can save water loss from deep penetration, more water will be lost by evaporation.

Problems of drainage should be considered along with irrigation. Poor drainage inhibits growth of desirable pasture plants and encourages water tolerant weedy species. Poorly drained pastures are so slow to dry out after irrigation that the likelihood of grazing while wet is increased. Salts may accumulate under poor drainage conditions in some of the arid regions. Careful preparation of the land for irrigation is the best method of avoiding improper drainage. Some of the adobe soils of lacustrine origin in the Sacramento Valley present a drainage problem because the soil is very heavy and extremely flat so that downward percolation is almost nonexistant. If good drainage is not possible, the choice of species for the pasture should include only those capable of growing on wet land. Bartels *et al.* (1932) have pointed out the importance of the method of irrigation upon the balance of species in the pasture. Ryegrass and white clover were more favored by frequent heavy waterings than cocksfoot and subterranean clover.

Ladino clover, alfalfa and other legumes may "scald" if irrigated during extremely hot weather. The difficulty usually occurs on impervious soils on still days when temperatures exceed 100°F. and water stands for several hours. This difficulty is avoided by providing good drainage and by irrigating at night during very hot weather.

4. Fertilization

In the United States, fertilizers have been used less extensively on irrigated pastures than on most cultivated crops. In recent years, however, experimental studies have shown large increases in yield are obtained from the fertilization of pastures under many conditions. According to Hamilton *et al.* (1945) the average farm in the irrigated west produces enough barnyard manure to provide 8 to 10 tons per acre every 3 years. Robertson *et al.* (1948) in Colorado recommend top dressing with manure in February or March to provide 2 weeks more of early spring grazing. Boyd (1945) in Wyoming suggests using 8 to 10 loads of manure every few years, applied in fall or winter. Klages *et al.* (1948) consider top dressing with manure the best fertilization for pastures, supplemented with phosphorus (40 to 50 lbs. P_2O_5 per acre) in southern Idaho and with sulfur (100 lbs. gypsum per acre) in parts of northern Idaho.

It is generally recognized that manure stimulates the growth of grasses more than legumes (Bateman, 1940; Hamilton *et al.*, 1945; Klages *et al.*, 1948; Schoth, 1944). To maintain a vigorous growth of legumes in pastures that are manured, phosphate fertilizer should also be applied. Schoth (1944) recommends 8 to 10 tons manure per acre, supplemented with 300 lbs. superphosphate or the equivalent. Bateman (1940) recommends that farmers in Utah apply 10 to 15 tons manure with 200 lbs. "treble" superphosphate (43 per cent P_2O_5) to their pastures every 3 years. He reports that Pittman found that one application of 600 lbs. of treble superphosphate increased yields 63.6 per cent over a 5-year period, the gain the first season amounting to 211 per cent. He found that phosphorous fertilizer increased the nitrogen content of the herbage, by increasing the per cent legumes in the pasture. One application of treble superphosphate at 200 lbs. per acre resulted in a 22.7 per cent increase in the phosphorus content of the forage over a 3-year period. In another study Bateman (1943) found that one application of 6.8 tons manure with 200 lbs. treble superphosphate, applied to the pasture plots between March 27 and April 6, increased the first grazing 27 per cent, the second grazing 108 per cent, the third grazing 117 per cent, the fourth grazing 102 per cent, and a small fifth grazing 187 per cent, the year's gain amounting to an increase of 95.7 per cent. Ewalt and Jones (1939) report a 75 per cent increase in production over a 5-year period from annual applications of 300 lbs. superphosphate (16 per cent P_2O_5). This treatment did not alter the chemical composition of ladino clover in the pasture.

Pittman and Bennett (1948) in a study of irrigated meadow pastures in ranching areas of northern Utah, report a 50 per cent increase in production from either 10 tons manure or 200 lbs. ammonium sulphate per acre. One application of manure stimulated growth through 4 years. Applications of 200 lbs. treble superphosphate per acre were profitable where legumes were abundant. Liquid manure containing some solids, urine, and barn washings is especially valuable pasture fertilizer (Hamilton *et al.*, 1945). Yearly applications equivalent to 10 tons of barnyard manure per acre may be used in light applications after each grazing. Fertilization costs may be much reduced if the manure can be applied with the irrigation water.

The rapid development of irrigated pastures in Victoria, Australia is attributed by Bartels and Morgan (1944) to the universal response of these pastures to phosphate fertilizer. At Werribee, Morgan (1949) reports profitable responses from applications of superphosphate (22 per cent P_2O_5) at 400 to 500 lbs. per acre per year if moisture is not limiting, and under similar conditions Rayner (1941) recommends 400 lbs. Annual applications of 200 lbs. superphosphate increased production 77 per cent with 6 irrigations totaling 2 feet of water per year (Australia, 1947). Additions of 100 lbs. ammonium sulphate, nitrate of soda, or potassium sulfate, or 3000 lbs. lime or gypsum, failed to increase yields further, and in some instances lowered them. Rock phosphate was found to be highly inefficient. In northern Victoria Morgan and Rayner (1941) recommended annual applications of 300 lbs. superphosphate. According to Bartels (1944a) many farmers apply as much as 500 lbs. superphosphate per acre to their pastures each year. Applying phosphorus at one time (in the fall) was as effective as several fractional applications during the year (Australia, 1947; Morgan, 1949; Rayner, 1941). Rayner (1947) found that liberal top dressings of superphosphate not only increased yield but fostered development of the more valuable species to the exclusion of weeds and other less desirable forage.

In a few instances pastures have responded to fertilizers other than manure and phosphorus. According to Schoth (1944) in Oregon, and Andrew (1947) in Victoria, potash has been profitably applied on some soils. Both Schoth (1944) and Klages *et al.* (1948) report beneficial responses from sulfur on some soils of Oregon and northern Idaho. Although the response to manure and phosphorus is widespread, use of other fertilizers should be based on prior tests conducted on the land.

5. Molybdenum Toxicity

Britton and Goss (1946) reported an ailment in cattle and sheep which had been prevalent for many years along the southwest edge of San Joaquin Valley in central California. Ingestion of green feed containing abnormally high quantities of molybdenum was found to be the cause. The symptoms in cattle are excessive scouring, loss of weight and roughening and gradual fading of the hair. Loss of hair and eventual death of the animal may result. Ferguson *et al.* (1943) and Lewis (1943a, 1943b) have reported a similar condition in England. Barshad (1948) has shown that, in general, abnormality in cattle occurred when a large portion of the pasture plants contained 20 or more parts per million of molybdenum but no difficulty was observed if less than 10 p.p.m. was found. Analysis of soils in the affected area of California indicated the molybdenum content was only slightly higher than normal soils although the solubility was relatively high. The alkalinity of these soils was responsible in part for the high solubility.

Legumes growing on affected soils absorb greater quantities of molybdenum than grasses. *Lotus corniculatus* and *Trifolium repens latum* contained as much as 150 p.p.m. dry matter compared with 33 p.p.m. in *Lolium perenne* and 9 p.p.m. in *Paspalum dilatatum*. The total molybdenum content of soils ranged from 5 to 10 p.p.m. where these samples were taken, but Barshad (1948) points out that cattle may be affected on soils containing as little as 1.5 p.p.m.

Grazing and livestock management systems for control of molybdenum poisoning are as yet based upon limited evidence and only partially published. Barshad (1948) states that feeding of dry roughage tended to reduce scouring. Rotation of livestock between badly affected and less badly affected areas has been suggested. Emrick (1948) recommends a special pasture mixture from which legumes are eliminated for soils that may contain excessive amounts of molybdenum.

Use of copper in the form of copper sulfate in the drinking water has been successful in overcoming molybdenum poisoning in some instances according to an unpublished report of the California Agricultural Experiment Station. Acidifying the soil with sulfur or other acidifying materials has been suggested as a method of reducing the availability of molybdenum. The use of nitrate fertilizer has reduced the uptake of molybdenum and its value on a field scale should be determined.

Even though very low concentrations of molybdenum in the soil may be taken up by plants in concentrations that become toxic, the element is essential to plant growth, and particularly to thrifty development and nodulation of legumes. Anderson (1946) has shown that some soils of south Australia are so deficient in molybdenum that applications of 1 or 2 ounces per acre were associated with very large increases in forage, particularly on land not deficient in phosphorus.

6. *Weed Control*

Annual weeds are seldom, if ever, a serious problem in well-managed irrigated pastures, particularly if the initial establishment is good. Occasionally pastures become infested with perennial thistles or other unpalatable perennial weeds. It is not advisable to seed pastures on land known to be badly infested with weed seeds. Management practices which help to keep weeds under control are fertilization, careful irrigation, and mowing. Scattered weeds can be removed with a sharp shovel. If the infestation is general, resulting in greatly reduced productivity of the pasture, it is advisable to plow and return the land to row crops or fallow until the weeds are controlled.

According to Hamilton *et al.* (1945) many perennial weeds that commonly occur in pastures will be eaten by cattle if mowed about 2 days before the end of a grazing period. In the Intermountain Region irrigated pastures often become infested with dandelion (*Taraxacum officinale*). Dandelion can be controlled in pastures by spraying with 2,4-D, without permanent damage to legumes, but whether this is a practical measure is not now known. Spraying has been used with some success on curly dock (*Rumex crispus*) in California.

VI. Economy of Pastures

1. *Productivity*

The carrying capacity and productivity of irrigated pastures have been measured and reported in various ways. Methods for evaluating pasture research have been reviewed by Ahlgren (1947) who emphasized the advantages of using grazing animals. Comparison of results from different experiments is often complicated by the variety of measuring units used. Some effort has been made to standardize the measuring and reporting of grazing studies (Report, 1943).

Production in terms of live weight gains of lambs and steers was between 400 and 500 lbs. per acre of irrigated pasture in studies conducted on farms in the Sacramento Valley in California (Burlingame, 1949). Albaugh and Sullivan (1949) in Monterey County, California compared gains per acre made by cows and calves on irrigated pasture with gains per acre on alfalfa cut and fed green in the dry lot. Gains on pasture alone were 458 lbs. per acre compared with gains on alfalfa of 581 lbs. Over 2,000 head of cattle were used in this study. Bartels (1944a) in Australia reports gains from young sheep of over 1,000 lbs. per acre per year.

Burlingame (1949) in California obtained production records of dairy cattle, sheep and beef cattle on irrigated pasture through the use of "Animal unit months." All classes of livestock were compared on the basis of total digestible nutrients required per day. Morrison's feeding standards were used with minor rounding for ease of calculation. An Animal unit month (A.U.M.) was estimated to be 400 lbs. T.D.N. for a mature cow giving 200 lbs. of butter fat per year. He found that irrigated pastures in the Sacramento Valley had an average production of 10 A.U.M. per acre. Over 90 per cent of the pasturage obtained was during the eight-month period of March through October.

Bateman and Packer (1945) report pasture production of 253 standard cow days per acre, over a 3-year period. This is an equivalent of approximately 4 tons alfalfa hay per acre. A standard cow day was taken to equal 16 lbs. T.D.N. as proposed in the Preliminary report on pasture investigations technique (Report, 1943). In another study Bateman *et al.* (1949) found that an unimproved pasture, without fertilization, produced 2,921 lbs. T.D.N. per acre, or 183 standard cow days of grazing (4-year average). This pasture was fertilized with 5 tons manure and 87 lbs. 43 per cent phosphate annually and yielded 4,111 lbs. T.D.N., or 257 standard cow days of grazing annually during the following 5 years. New mixtures now being studied, with fertilization, yielded 5,204 lbs. T.D.N., or 325 standard cow days of grazing. This production is equivalent to 5.1 tons alfalfa hay per acre, and with a herd averaging 366 lbs. butter fat per year amounted to 230 lbs. butter fat per acre.

In a 5-year study of some improved dairy pastures in Utah, Rich *et al.* (1950) report an average of 303 standard cow days of grazing by high producing cows during a grazing season averaging 156 days per year. The alfalfa hay equivalent averaged 4.85 tons per acre and in different seasons ranged from 4.42 to 5.43 tons.

Annual production of good irrigated pastures ranged from 20 to 25 tons green weight in Australia (Andrew, 1947; Rayner, 1947). Bartels (1944a) reports experimental plots yielding 31 tons green weight per acre from 12 clippings. Unpublished data from experimental plots in California showed a range from 22.1 to 35.8 tons green weight per acre, depending upon the mixture. In Utah, with a comparatively short grazing season, new mixtures in experimental plots have yielded 16 to 17 tons per acre green-weight, according to Bateman *et al.* (1949) but with identical treatment the mixture in general use in the area produced only 10 tons. The data are based on 4 clippings, each preceding a grazing period. Jones and Brown (1949) state that an irrigated pasture should yield as large a tonnage of feed per acre as alfalfa, although there may be a few exceptions.

2. Economic Studies

Initial costs for developing irrigated pastures for flood irrigation include surveying, leveling, land planing, construction of irrigation ditches, drainage ditches and levees, turnout structures, seedbed preparation and seeding. As of 1948, the total costs of preparing land for flood irrigation by the strip-check method varied from $30 to $130 per acre in California (Jones and Brown, 1949). Total annual costs of production of established irrigated pastures ranged from $17.43 to $58.35 per acre for different operating units in the Sacramento Valley in 1948 (Reed and Geiberger, 1948; Burlingame and Kolb, 1948). Cost items included labor, materials such as irrigation power and fertilizer, taxes, general expenses, depreciation and interest on the investment.

Burlingame (1949) found that labor for irrigation, fencing and other purposes accounted for slightly over one-fourth of the total costs per acre. Interest on land values, facilities, and the pasture stand approximately equaled labor costs. Total costs averaged $32.62 per acre on 24 records totaling 1,188 acres in 1947, as shown in Table V. On an average, a little over 60 per cent of total cash and labor costs was for water and irrigation labor. Water costs ranged from about $2.00 per acre on land in some irrigation districts to over $20.00 where pumping from considerable depths was required. Irrigation labor varied from

TABLE V

Principal Items of Cost in the Production of 24 Irrigated Pastures Totaling 1,188 Acres in the Sacramento Valley, 1947 [a]

Item	Cost
Labor for irrigation, fencing, etc.	$ 8.67
Water costs, fertilizer, and other materials	6.90
Taxes and general expenses	3.42
Depreciation on stand, irrigation system, etc.	4.88
Interest on land values, facilities, and stand	8.75
Total cost per acre	$32.62
Animal unit months of pasturage per acre	9.4
Total cost per animal unit month	3.48

[a] Burlingame (1949).

less than $3.00 to more than $17.00 per acre depending upon the method of irrigation, size of head of water, and efficiency of the irrigation system. Irrigated pastures have decided economic advantage in regions of abundant cheap water and relatively level land.

Total costs per acre are of much significance only when considered in relation to productivity. Gorton (1941), Burlingame and Kolb (1948), and Hedges (1948) have shown that high producing pastures usually have lower costs per unit of feed produced than low producing pastures although total costs per acre may be higher. Three California studies are reported in Table VI. Burlingame and Kolb (1948) obtained costs ranging from $1.60 to $8.61 per Animal unit month (A.U.M.). Differences in productivity were primarily responsible for this range. These average costs per A.U.M. were used to calculate the equivalent value of alfalfa hay per ton on the basis of equal amounts of total digestible nutrients from the pasture and alfalfa. The alfalfa hay averaging 50 per cent total digestible nutrients could cost only $10.73 per ton to equal the average cost of $4.28 for an Animal unit month. The seasonal average price of alfalfa hay in California during this same year (1948) was $22.10 per ton. Gorton (1941) found that in Oregon, costs per acre decreased as the size of the pasture increased. The production of pastures also decreased with increasing size, however, resulting in the size of pastures having little or no relationship to costs per unit of production.

TABLE VI

Irrigated Pasture Costs per Acre and per A.U.M. in the Sacramento Valley, California in 1948

Author	No. units studied	$ Cost per A.U.M. Low	High	Av.	Equiv. value Alfalfa per ton [a] $	Av. total cost per acre, $
Reed and Geiberger (1948)	3	3.00	5.55	3.58	8.95	37.59
Burlingame and Kolb (1948)	9	1.60	8.61	4.23	10.57	25.07
Hedges (1949)	17	2.90	7.02	5.05	12.63	30.82
Average	—	2.50	7.06	4.28	10.73	31.16

[a] Calculated on the basis of 400 lbs. total digestible nutrients per A.U.M. at average costs indicated in table.

Seventy-nine dairy records obtained in 1947-1948 were reported by Shultis and Miller (1949) in the San Joaquin Valley and classified according to high and low use of pasture for market milk dairies and manufacturing milk dairies. The market milk dairies making high use of pasture showed an advantage over those making low use of pasture, amounting to $33.99 per year in feed costs per cow and $28.31 profit per cow. Corresponding comparisons for manufacturing milk dairies was $24.62 advantage in feed costs and $42.24 greater profit per cow. For both types of dairies the pounds of butterfat sold per cow were greater under low use of pasture but added costs for hay, concentrates, silage and green feeds decreased profits.

Bateman and Packer (1945) have reported production and cost studies on the Utah Agricultural Experiment Station Dairy Experimental Farm herd. A summary of their 3-year study is reported in Table VII. On the basis of butterfat at $.90 per lb., they obtained a return of $5.15 per dollar of production cost, and a gross return, above feed production cost, of $149.39 per acre. They conclude "that pasture, when planted on fertile soil and well managed, is an economical feed for the production of milk and butterfat and gives a high return per acre when grazed by good dairy cattle."

Albaugh and Sullivan (1949) made a direct comparison of costs of pasture feeding and feeding of green alfalfa hay to beef cattle in the dry lot. The alfalfa was mowed daily, mechanically loaded, hauled by truck to the feed lot and unloaded by hand. Costs per 100 lbs. gain

TABLE VII

Per Acre Returns from Pasture; Utah Agricultural Experiment Station Dairy Experimental Farm [a]

Item	3-Year average
Standard cow days of grazing [b]	253
Supplemental feeds fed: alfalfa (lbs.)	1127
grain (lbs.)	1707
Gain in body weight (lbs.)	224
Total production: milk (lbs.)	8704
butterfat (lbs.)	303
Butterfat produced from supplement feeds fed (lbs.)	98
Production from pasture: milk (lbs.)	5909
butterfat (lbs.)	206
Value of butterfat produced from pasture at $.90 per lb.	$185.40
Production cost per acre	36.01
Gross return above feed production cost	149.39
Dollars returned for each dollar cost of pasture production	5.15
Pasture feed production cost of 1 lb. butterfat	.18

[a] Bateman and Packer (1945).

[b] A standard cow day is defined as an animal obtaining 16 lbs. of total digestible nutrients from pasture per day.

were less on pasture than from dry lot feeding of green alfalfa. Although the alfalfa produced more feed per acre, costs of harvesting and feeding more than offset this advantage. After considering purchasing and selling prices, pasture feeding was the more profitable.

Hedges (1948) studied 17 pasture units in the Sacramento Valley ranging in size from 60 to 490 acres. In these studies gains from beef cattle and lambs were obtained in addition to costs and carrying capacities. This method avoided the limitations of the above reported studies of carrying capacities which provided no information on costs in relation to gain in weight or milk production. Gains per acre ranged from 154 to 440 lbs. per acre with an average of 275 lbs. Animal unit months per acre averaged 6.1. Costs per 100 lbs. gain ranged from a low of $6.47 on a 440 acre unit to a high of $14.94 on a 310 acre unit. Average costs per 100 lbs. gain was $11.20.

3. Effect of Pastures on Crops that Follow

The beneficial effects of sod crops on soil structure, and fertility have been extensively investigated by many State Experiment Stations. There apparently have been no studies conducted specifically with irrigated pastures in crop rotations. General farm practice has been to maintain pastures so long as they are productive. Many irrigated pastures in California are still producing satisfactorily after 20 years.

However, several writers have emphasized the importance of using irrigated pastures in a rotation and have mentioned increased yields of crops which follow (Klages *et al.*, 1948; Robertson *et al.*, 1948; Starke, 1947; Bartels, 1944b; and Hamilton *et al.*, 1945). Klages *et al.* further mention that sweet clover with mountain brome leaves the soil in better condition for the crops to follow than sweet clover alone when these plants are used for temporary irrigated pastures. These writers also suggest that 4 years are usually long enough for a field to remain in pasture, although the exact length of time may be influenced by many factors.

VII. Pastures in Relation to Other Sources of Feed

1. *Relation to Other Forage Resources*

Irrigated pastures are depended upon as the sole source of forage in relatively few areas. Throughout the western United States they are used most extensively for dairy cattle. Irrigated pastures are used to supplement the range in the production of both beef and sheep. Guilbert and Hart (1946) report that one and a half million beef cattle and calves derived 13 per cent of their feed from 150 thousand acres of irrigated pasture, while also harvesting the forage from 40 million acres of range land. About half as many dairy cattle utilized the forage from 224 thousand acres irrigated pasture and one million acres of range, while nearly 3 million sheep grazed 120 thousand acres of irrigated pasture and 18 million acres of range. The use of irrigated pastures for the production of beef and sheep is increasing in the western United States.

Throughout much of the western range country beef cattle are wintered on wild hay produced on irrigated mountain meadows. The common practice is to remove the cattle from the meadows as early in the season as forage is available on the spring ranges. The meadows then produce a crop of wild hay which is cut in midsummer. The aftermath is grazed by the cattle after they return to the home ranch in the fall. The cattle remain on these meadows throughout the winter, being fed the wild hay produced there. Stewart and Clark (1944) found that greater total yields, and higher quality forage were produced when the meadows were grazed 20 to 35 days longer than customary in the spring, and the hay crop cut at the bloom stage, which is earlier than most ranchers harvest. This practice benefited spring ranges by reducing grazing on them, and at the same time kept the animals at the home ranch during calving and immediately after, allowing the rancher to give them better care than when they are on the range. Stoddart (1944) reported that in northern Utah dairy bred heifers did not make as good gains on summer range as beef, but that they did make satisfactory development for subsequent milk production. Collins (1945) has reported the successful operations of several ranchers in improving the productivity of their irrigated mountain meadows.

Jones and Mumford (1944) in Oregon, recommend sudangrass as a supplement to permanent pasture in late summer, and Abruzzi winter rye for late winter and early spring on well drained land. In South Africa, Bonsma (1947) found winter cereals, where adapted, a cheaper source of succulent feed for dairy cows than silage. Madson and Love (1948) report that in California silage is made from a variety of crops, but that while pasturage is available it is a much more economical source of feed. In Australia, Bartels (1944b) reports the effective use of a number of annual forage crops, both as a supplement to irrigated pastures and to take livestock from nonirrigated areas through drought years. Corn, millets, and sorghum have been used for this purpose.

2. Supplemental Feeding

Jones and Brown (1949) recommend having dry roughage available to cattle and sheep at all times while on irrigated pasture, to reduce bloat and increase dry-matter consumption. Jones and Mumford (1944) point out that the capacity of a dairy cow to consume green forage is limited, and that high producing cows on pasture will require a supplement of grain for maximum production. If cows on pasture are liberally fed such supplements as ryegrass hay or corn silage, some protein concentrate may be needed, in addition to grain. According to Klages *et al.* (1948) dairy cows will produce one lb. of butterfat daily and maintain body weight on irrigated pasture alone but production is increased if alfalfa hay is also fed. Hamilton *et al.* (1945) recommend feeding an increasing amount of concentrate to high producing cows, as the productivity of the pasture declines. Ewalt and Morse (1942) and Bateman (1945) have prepared tables to guide dairymen in feeding grain to cows on irrigated pasture.

Beef cattle will make excellent growth on irrigated pasture without any supplements. Carbohydrate concentrates are frequently used in the fattening process.

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