Department of Agronomy and Range Science
UNIVERSITY OF CALIFORNIA, DAVIS

RANGE SCIENCE REPORT

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SUBCLOVER RESPONDS NEGATIVELY TO APPLIED NITROGEN WHEN COMPETING WITH ANNUAL GRASSES

M. B. Jones and W. H. Brooks[1]

ABSTRACT

Nitrogen is sometimes applied to subclover-grass (*Trifolium subterraneum* L.) pastures in northern California and Oregon to increase herbage growth in winter, or on new seedings where soils are very low in available N. The objectives of these studies were: (1) to measure the effect of applied N on subclover yield when grown alone and with competing grass in a pot study; and (2) to measure the effect of N on seedling survival and forage production into the second year under field conditions. In the pot study where subclover was grown without competition it did not respond to 5 ppm N, but did respond to 10 and 20 ppm rates. Higher levels gave no additional growth. However, where subclover and grass were sown together, the grass responded linearly up 60 ppm N, but subclover yields were unchanged or depressed by any applied N. In the field, the number of seedlings that survived until spring was depressed by applied N, and in the second year total forage yields were higher with applied PS than with NPS. The percent subclover in the stand was also depressed the second growing season. Since it has been shown that 5600 lb/a of subclover-grass pasture produced as much lamb/a as 8000 lb/a of rye grass, and that lamb growth rates are positively correlated with the percentage of subclover in a pasture, it appears counter productive to use N on subclover.

INTRODUCTION

Nitrogen is nearly always deficient on California annual grasslands, and to increase herbage growth N levels must be increased by the use of legumes or with N fertilizers. The manufacture of fertilizer N requires the input of fossil fuel energy, and it should be used judiciously in order not to pollute the ground water (Jones, et al. 1974). Fall applied nitrogen fertilizer has

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been shown to increase winter forage production on California annual grasslands (Jones 1960, Martin and Berry 1970). This is a time when pastures are short and the carrying capacity during the winter determines the carrying capacity of the ranch. Pastures with good stands of subclover (*Trifolium subterraneum* L.) (i.e., >20%) also increase winter growth equivalent to applying 40 to 60 lb/a N (Jones 1967). However, additional winter growth can be obtained if N is applied to the subclover-grass mix (Cannon 1988). This is to be expected since most N fixation occurs when soil N levels are inadequate (Allos and Bartholomew 1959, Williams, et al 1989).

The objectives of these studies were: (1) to measure the effect of applied N on subclover yield when grown alone and with competing grass in a pot study; and (2) to measure the effect of N on seedling survival and forage production into the second year under field conditions.

METHODS AND MATERIALS

Experiment 1. Pots containing one kg of Josephine soil were fertilized with 100 ppm P as NaH2P04, and 40 ppm S and 97 ppm K as K2S04. Nitrogen was applied as Ca(N03)2 at 0, 5, 10, 20, 30, and 60 ppm N. Each of these treatments were planted with 10 subclover seeds alone (0.046 g/pot), or subclover with 0.07 g of soft chess (*Bromus mollis* L.) seeds on January 29. The subclover was inoculated with WR inoculum from the Nitrogin Co., except an extra zero N treatment was left uninoculated. The plants were clipped March 10. Each of the 14 treatments were replicated four times.

Experiment 2. In October 1969 Mt. Barker subclover was seed on Sutherlin loam soil with a rangeland drill in rows 12 in. apart at 20 lb/a on Sutherlin loam soil in Anderson Valley, California, that had been previously closely grazed to remove dry forage. The area was fertilized with 285 lb/a of 0-35-0-20S. There were five levels of N (0, 10, 20, 40, and 80 lb/a) applied as urea, each replicated four times. On April 2, 1970, visual estimates of the percent subclover in the stand of grass and other forbs was made.

Experiment 3. In October 1970 Mt. Barker subclover was seeded with a range drill on Pinole sandy loam in Potter Valley, California using six fertilizer treatments: 1) Check, 2) N, 3) P, 4) S, 5) PS, and 6) NPS, each replicated four times. Nitrogen was applied at 80 lb/a as urea, P at 40 lb/a as triple superphosphate, and S at 40 lb/a as elemental 5. The number of seedlings per three ft. of row were counted in January 1971, and total forage production was measured in May 1972.

RESULTS

Experiment 1: The effect of N on yield of subclover growing alone and with soft chess, and soft chess growing with subclover is shown in Figure 1. The yield of uninoculated subclover alone or with grass was about 0.4 g/pot, and with inoculation the values increased to about 0.7 g. The application of 5 ppm N to clover growing alone did not change the yield, 10 ppm increased the yield to nearly one g/pot, and 20 ppm gave a yield of 1.5, with no further change with additional N. N applied to subclover growing with grass tended to depress the growth of subclover slightly. The yield was 0.5 g with 60 ppm N.

The yield of soft chess growing with subclover responded linearly to N, with 0.3 g at zero N and 1.7 g at 60 ppm.

Inoculation increased percent N in the subclover from 3.0 to 3.5%, but the application of N on subclover growing alone or with soft chess made little consistent difference (Figure 2). The percent N in the soft chess was less than half that in the clover, and applied N made little difference in grass N percentages.

The uptake of N by uninoculated subclover was 10 mg/pot. Inoculating the clover increased the value to 26 mg. Application of 5 ppm N did not increase the uptake of N by clover growing alone. Applying 10 ppm N increased the uptake value to 34 mg, and 20 ppm N increased the uptake to 38 mg. There was little change in uptake with additions of N greater than 20 ppm. With subclover growing with grass, the application of N gradually decreased the uptake of N from 25 mg/pot with no N applied to 17 mg/pot where N was applied. The uptake of N by the soft chess increased with each increment of N from 5 mg N where none was applied to 32 mg where 60 ppm was applied.

Experiments 2 and 3. Under field conditions applications of N at the time of seeding subclover on a Sutherlin soil reduced the percent of subclover in the stand (Figure 4). There was a negative correlation between the amount of N applied and the percent of subclover in the stand ($r = 0.91$).

In a similar study on Pinole sandy loam, the number of seedlings per three feet of row was reduced by N alone, and by NPS compared with PS in the first spring after seeding (Figure 5). Phosphorus and S applied separately did not influence the seedling count, but when applied together there were more than in the check. In the second growing season forage yields were increased above the check treatment by various combinations of N, P, and S, but PS together produced a higher yield than any other combination (Figure 6).

DISCUSSION

The data from the pot experiment indicates that when growing without grass competition subclover yields increased 53% with a moderate application of N (20 ppm), but that additional N gave no further increase. However, when subclover was growing with grass in the same pot, applied N increased grass growth and tended to depress clover growth. The applied N caused little change in N concentration in either subclover or grass.

It appears that the same type of response occurred in the field at both locations where N was applied to new seedings of subclover. The more N applied the lower the clover percentage in the stand. These negative effects can be moderated by grazing (Greenwood, et al. 1967). Jones and Evans (1960) reported that after applying 50 lb N/a with P for two consecutive years, only two percent subclover remained in an established subclover stand compared with 15% where P only was applied on ungrazed plots. Where sheep were allowed to graze the respective values were 18 and 26%.

Although more total forage production can be expected by applying N to grass-subclover pastures, the realization of increased animal production from this forage N response may be questioned. Jones, et al. (1987) reported that ryegrass fertilized with N, produced about 8000 lb forage/acre, and produced about the same lamb gain per acre as about 5600 lb forage/a subclover-grass.

The number of lambs/acre were set so that each lamb had access to an average of 218 lb forage/a from February 14 through May 10.

Davies, et al. (1966) studied the effect of N fertilization of subclover-grass pasture on sheep production. Three levels of ammonium sulfate (0, 56, and 150 lb/a) were applied as a split dressing each year at emergence and in late winter for four years. There were two stocking rates -- 3.5 and 5.0 sheep/acre. The first year, ammonium sulfate increased liveweight of the sheep as well as wool production, in autumn and winter. In the last two years of the study, the sheep grazing the N fertilized plots lost more weight in autumn and winter, and produced less wool per head than sheep on pastures receiving no N. Wool per acre was less from the heaviest N fertilized pasture in the last year of the study than from the check. This loss of animal production was due to loss of subclover and low protein in the forage on offer (Greenwood, et al 1967).

Other studies have indicated that more autumn applied N is leached where N was applied to subclover than where it was applied to grass (Jones, et al 1974). This indicates that for best N use efficiency and to minimize ground water pollution, N should not be applied to good stands of subclover in the autumn.

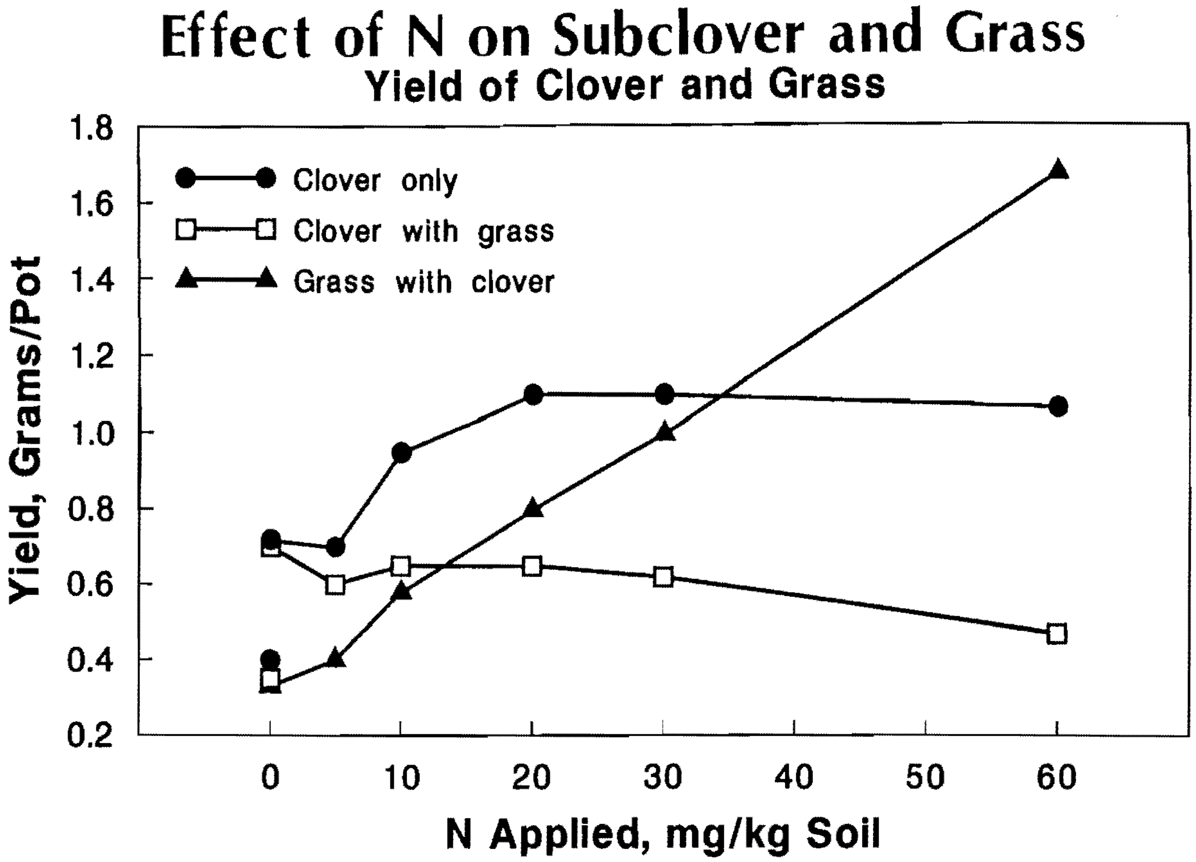

Figure 1

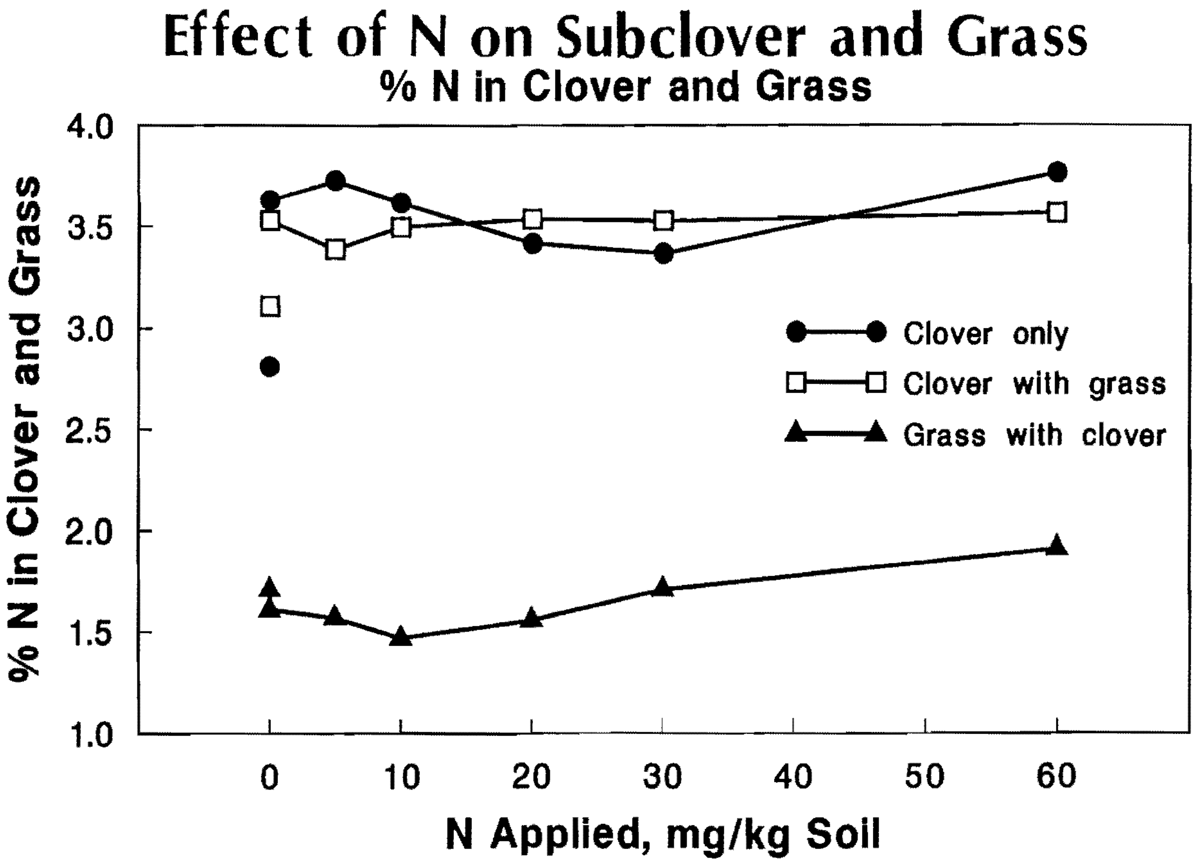

Figure 2

Effect of N on Subclover and Grass

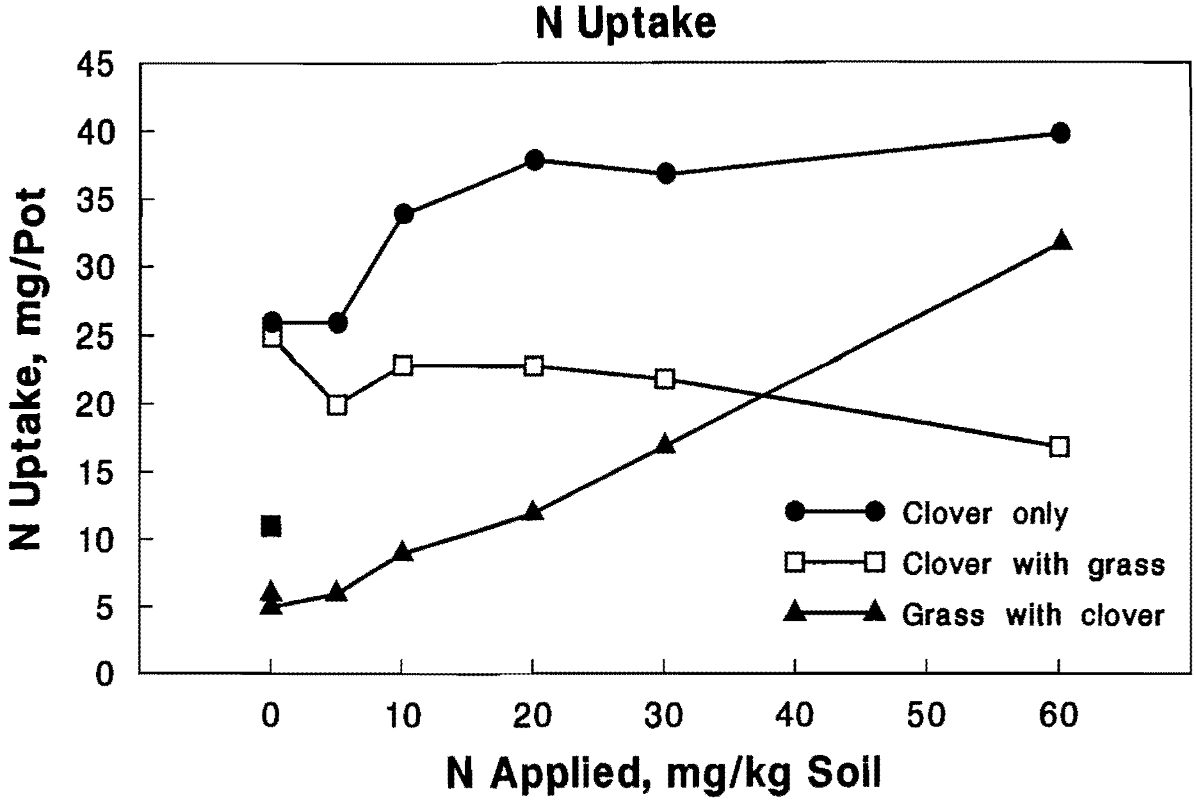

Figure 3

Effect of N on % Subclover

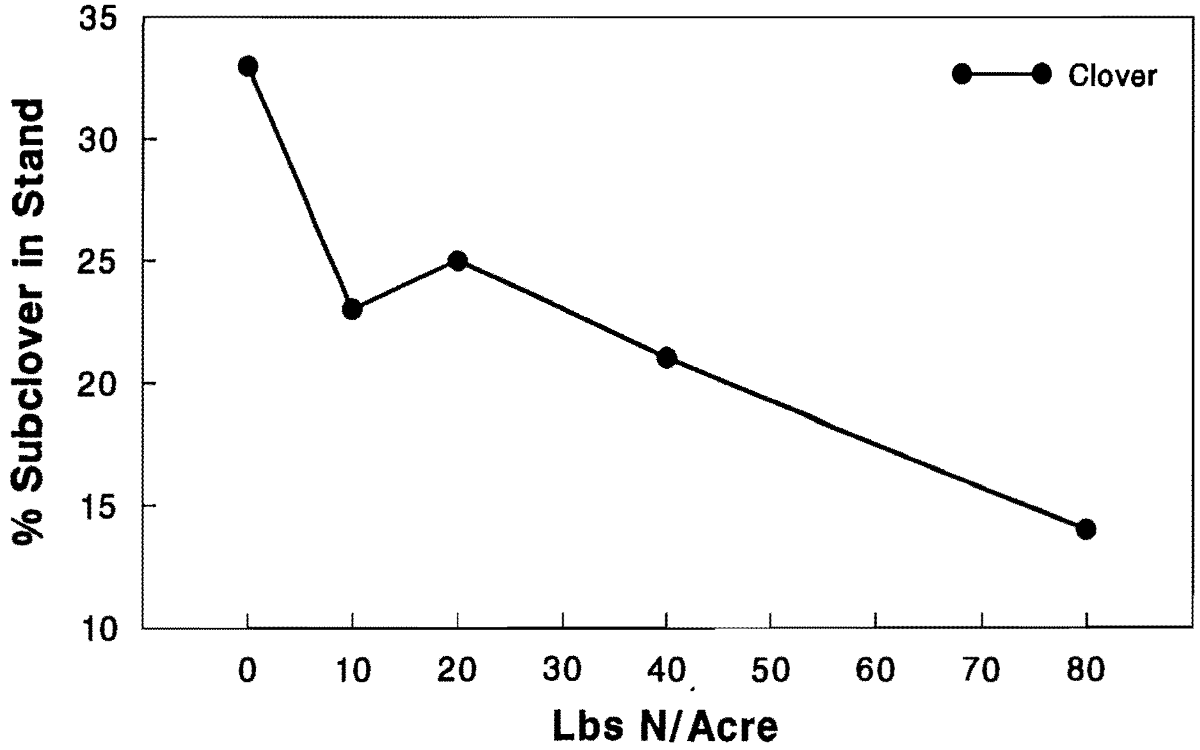

Figure 4

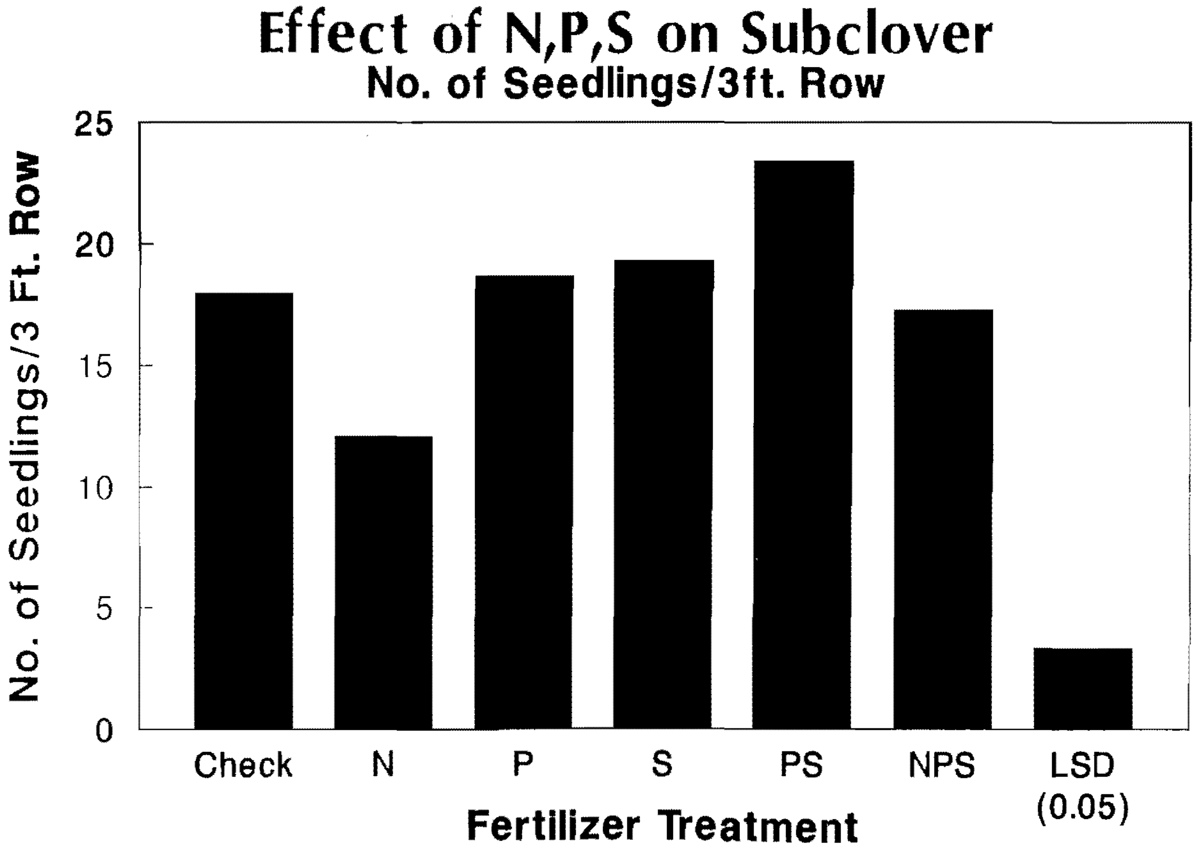

Figure 5

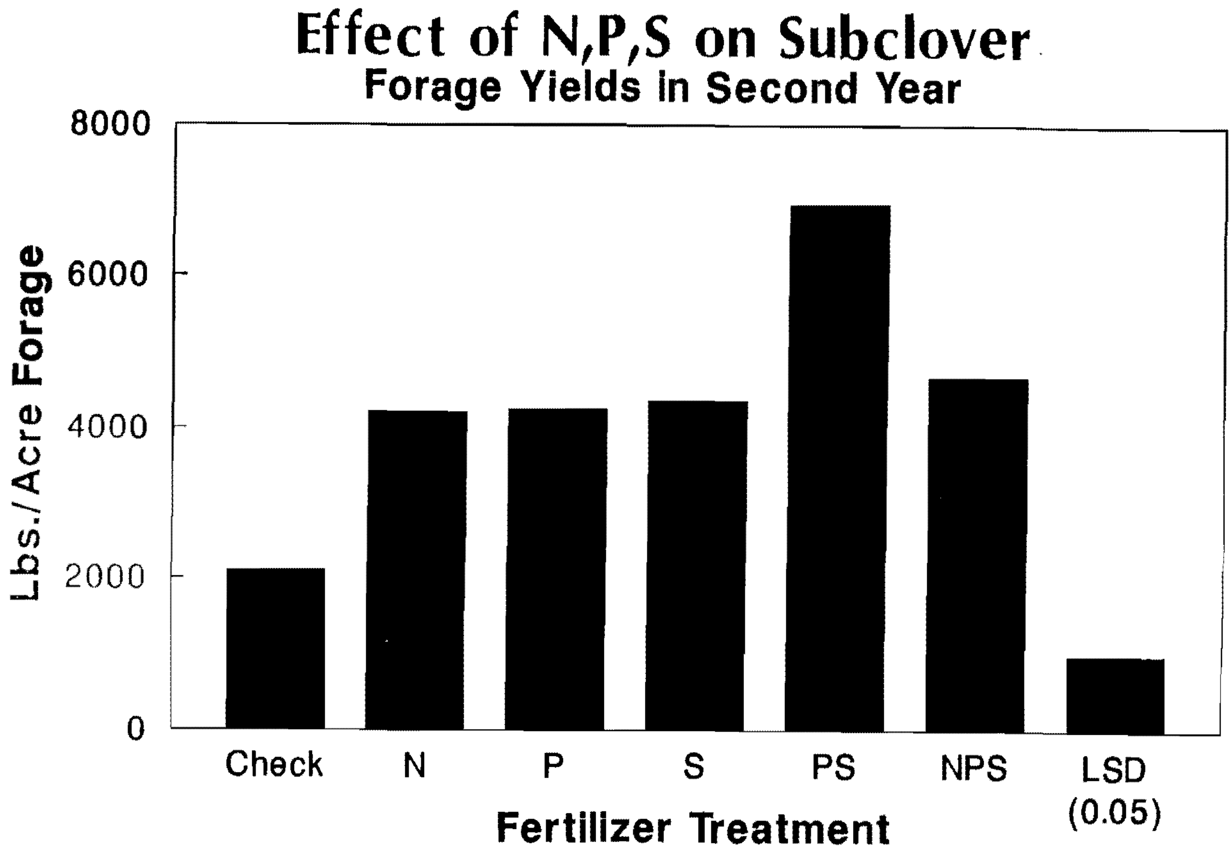

Figure 6

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RANGE SCIENCE REPORT

Agricultural Experiment Station

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Coping with Five Years of Drought in the Central San Joaquin Valley

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Five consecutive years of drought in the central San Joaquin Valley are creating a severe hardship for the livestock industry. Lowered forage production has resulted in residual dry matter well below the minimum threshold levels for California. Residual dry matter is the dry plant material left on the ground from the previous year's growth that provides favorable micro-environments for early seedling growth, soil protection, soil organic matter, and a source of low quality fall forage for livestock (Clawson, McDougald, and Duncan 1982).

Currently low residual dry matter levels resulting from continuous drought are creating a situation similar to that following a wildfire. Besides reducing the current year's forage, a wildfire reduces the forage production in the following season and shortens the length of adequate green forage period. Stocking rates thus need to be reduced. In the growing season following a fire, forage production will be reduced by 30 to 50 percent and species composition will shift primarily to forbs. In the second growing season, forage production will still be about 20 percent less than on unburned sites. Only in the third growing season after a wildfire will forage production resemble that of unburned sites (McDougald, Frost, and Clawson 1991).

Sound rangeland and livestock management strategies can help the livestock producer endure the drought. As no specific management program can be applied in all situations, each recommendation should be carefully evaluated in terms of cost in relation to expected return. Each livestock operation must evaluate its management options and select those best suited to its specific situation. The following is a series of range and livestock management recommendations that may be considered.

Range Management

Move cattle to pastures with scattered blue oak. In much of the state, early season forage production and total forage production is greater beneath the canopies of blue oak than in adjacent open areas.

Visually evaluate the available forage remaining in each pasture. Map these areas into categories of high, moderate, and low forage following the guidelines for residual dry matter (Clawson et al. 1982, Frost et al. 1988). Use these maps to locate supplemental feeding areas and electric fencing to improve livestock distribution so existing forage or residual dry matter will be used efficiently.

Use nitrogen fertilization if and when rains occur. Nitrogen results in a quick forage production response and increases the quantity of protein in the forage. For best results, nitrogen should be applied to open rolling sites. The benefit of fertilization may be limited in areas of low average rainfall.

Poisonous plants become a bigger problem during drought. Locate all areas with poisonous plants and monitor them closely or exclude cattle from them if possible. Hungry animals will eat poisonous plants that they normally do not consume.

Utilize pastures with predominantly south and west aspect early in the grazing season. The forage on these areas will mature and dry earlier than that on north and east exposures. This grazing strategy will lengthen the period in which adequate amounts of green forage is available.

Swales, due to their deeper, more fertile and better water holding soils, are the highest forage producing sites on annual rangeland. However, during winter the cold air settles into the low areas, restricting plant growth. By fencing large swales and restricting their use until temperatures are warm, the plants will be given a photosynthetic advantage enabling them to produce near their potential. Since plants on these areas are the last to mature and dry, delaying their use may further extend the period in which large amounts of high quality green forage is available.

Providing high quality and accessible water to livestock is extremely important under drought conditions. Consider developing all possible sources of water. This includes developing springs and seeps, installing water tanks, building ponds or reservoirs, and drilling wells. Hauling water short distances to permit harvesting the feed from certain areas may be necessary in some cases, but this should be used as a last resort as it is a costly, time-consuming, and temporary solution.

Supplemental Feeding

Supplemental feeding is normally practiced to maintain herd performance in reproductive rates and weaning weights. During drought additional supplemental feed is provided to replace lost forage production. Supplemental feeds provide additional protein and energy to cattle. Common protein-rich supplements include cottonseed, soybean, linseed, and safflower oil meals or products containing these feeds. Well-cured green leafy alfalfa hays cut in the early bloom stage are high in protein. These high quality hays will provide adequate protein for all classes of livestock when fed in adequate amounts.

Common high energy feeds include the grains such as barley, corn, milo, and wheat. Molasses is an excellent energy source and in addition acts as a binder to keep down dust in ground and pelleted mixes. It is also used to increase palatability of feed mixes.

Liquid supplements can be formulated to provide either protein or energy. These liquids are commonly used when adequate amounts of low quality dry forage are available. Under drought conditions requiring replacement for forage these supplement forms are not recommended unless they are provided along with low quality roughages. Liquid supplements should not be considered if it takes more than 2 pounds per cow per day to maintain desired livestock performance.

As animals are exposed to severe drought conditions for some time, their maintenance requirement will decrease and a lower feed level will be adequate (Table 1). Gradual reduction of feed levels is important as it will allow animals to adjust to the lower level with little pronounced effect. However, weak animals should not be allowed to decline in condition and become weaker because greater quantities of feed are then required to bring them back to good condition.

Feeding the standard daily requirements twice a week is more effective than daily feeding of reduced amounts. These less frequent large feedings allow the weaker animals, as well as the stronger animals, to get their fill. This will also save on labor costs.

Table 1. Submaintenance Diets – Daily Quantities for Various Classes of Cattle

Feed	Calves 6-12 months	Yearlings 12-18 months	Cows early pregnancy	Cows late pregnancy	Dry cows over 18 months
			(lb. per day)		
Legume hay	6-8	6-8	8-10	16-18	6-8
Grain	4	4	6-8	8-10	4-6
Grain	2-2.5	2-2.5	4.5-6.5	6.5-8.5	2.5-5.5
Legume Hay	1	1	2	2	1
Low quality dry roughage	6	6	12-16	16-20	6-12
Protein meal (41% protein)	1	1	1	1.5	.75
Grain	2-2.5	2-2.5	4.5-6.5	6.5-8.5	2.5-5.5
Low quality dry roughage	1	1	2	2	1
Protein meal (41% protein)	.25-.5	.25-.5	.5	.5	.25-.5

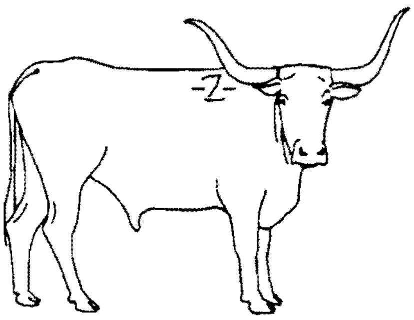
From Dunbar et al. 1987

During normal feeding conditions, animals deposit some of the essential minerals in their bones. During short deficiency periods these minerals are used. Under most dry feed conditions cattle should receive a calcium and phosphorous supplement. During prolonged drought it is even more important that cattle receive these two minerals. This is particularly important for young growing animals, pregnant females, and lactating heifers and cows. Vitamin A is critical during drought. Dry feed contains very little vitamin A. Vitamin A can be provided by having some green hay in the ration or by adding a stable form of vitamin A to the feed mix. Another option is injectable vitamin A. However, animals that have been on green pasture for some time usually will not experience vitamin A deficiency for 4 to 6 months when placed on a vitamin A deficient ration.

In drought conditions cattle may be fed a variety of feedstuffs. Low-quality roughages such as cereal, straw, milo or corn stover, and cottonseed hulls are good roughage sources. Poultry manure and litter are good sources of nitrogen.

When feeding the animals, reduce the distance the animals must travel as much as possible. Walking in search of feed and water can use up as much as 30 percent of the energy derived from feed. This should be balanced against the need to utilize existing range forage efficiently.

Extremely cold weather can also increase energy requirements. Under these conditions roughages, such as hay and straw, will produce more body heat than concentrated feeds, such as barley or corn.



Livestock Management

Formulate a selling policy to deal with classes of animals to sell and rate at which they should be placed on the market. Pregnancy check all heifers and cows, cull those that are open, and save the most desirable and younger cows. Carrying these on minimal rations will enable you to save valuable breeding stock and replenish the herd after the drought has broken.

Wean calves as soon as possible. Don't let heifers or cows get into poor condition. Weaning ages can be classified into three groups:

1. 6 months or older
2. 3 to 5 months
3. 6 weeks to 3 months

Calves weaned at 6 months or older perform well on high quality roughage. Calves 3 to 5 months can be raised on good quality hay and grain. Calves 6 weeks to 3 months require diets higher in grains and a higher quality of hay, but do not hesitate to wean calves, regardless of age, to save the cows.

Group the herd according to nutritional needs. This will allow for proper feeding of each group and provide an easier means of assessing livestock condition. The following is an order of priority:

1. Calves under 3 months
2. Lactating heifers
3. Calves 3 to 6 months
4. Lactating cows
5. Heifers or cows in the last 3rd of pregnancy
6. Calves 6 to 12 months of age
7. Calves 12 months or older
8. Heifers or cows in early and mid-pregnancy
9. Bulls

Groups low on the priority list can stand longer periods of nutritional stress. These animals should be given low priority in the feeding program. Those animals most likely to die during drought conditions are young calves and pregnant or lactating heifers and cows. These classes of animals should receive highest priority and be fed the best feed. Bulls should remain in fair condition except prior to the breeding season when condition needs to be improved.

Watch for buildups of internal and external parasites. Parasites can be a more serious problem on cattle under stress than under normal conditions. A good parasite control program will be even more important during drought. Make sure your cattle have internal parasites before you treat as deworming is expensive in labor and materials.

Assistance Available

The USDA Emergency Feed Program is initiated locally through the County Executive Director of the Agricultural Stabilization and Conservation Service (ASCS) when a substantial loss (greater than 40 percent) of livestock feed occurs. The program provides cost sharing for the purchase of supplemental feed. Information regarding this program is available by contacting your county ASCS office.

In formulating a supplemental feeding program to fit an individual operation, assistance is available from range and livestock professionals in the University of California Cooperative Extension.

Special income tax considerations are available to producers when livestock is sold due to drought. University of California Cooperative Extension specialists can provide educational materials describing various methods of determining your tax responsibility. However, it is always best to consult your accountant or tax advisor concerning the specifics of your case.

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Estimating Livestock Grazing Capacity on California Annual Rangeland

Neil K. McDougald, W. James Clawson, James W. Bartolome and William E. Frost

Efficient grazing use of annual rangeland requires a quick, efficient, yet accurate and repeatable procedure to set initial livestock stocking levels. Information collected over a 30 year period on the San Joaquin Experimental Range and other locations in the state has enabled us to develop an estimating technique that integrates the myriad of environmental factors that affect forage production and livestock use into a simpler subset of easily measured variables – slope and canopy cover.

The scorecards developed contain grazing capacities based on: (1) the productivity of a site, expressed as the relationship between forage production and canopy cover; (2) grazing use, expressed as the relationship between slope and grazing pressure; and (3) a level of residual dry matter or litter, which indicates allowable grazing pressure and utilization. These variables are displayed as a field scorecard which the experienced range manager can use to estimate grazing capacity on annual rangeland along with actual livestock grazing use history.

The scorecard is best used to determine an initial livestock stocking rate or to estimate proper levels of grazing use in combination with a slope and cover map of the grazing area. Slope classes can be readily mapped from topographic maps. The canopy classes can either be mapped from field observations and transferred to the slope class map or be determined from aerial photographs or vegetation maps, if available. Grazing capacity is then estimated from the acres present in each of the 16 classes and their respective number of estimated Animal Unit Months (AUMs) – Tables 1-3.

This procedure is most effective on rangeland with significant amounts of land in a mosaic of different slope and canopy classes. In pastures with little land in the most productive classes the system will significantly underestimate grazing capacity. Poorly distributed watering facilities and conditions hampering livestock travel may also lead to inaccurate grazing capacity estimates. Experienced range managers are urged to make realistic adjustments to account for long distances to water and poor travel conditions.

The scorecard is a compromise between detailed inventories of the important site factors and a procedure that can be practically applied. The system does not replace continued monitoring of actual use on an area, such as that suggested by Clawson (1990), which is the best method for determining grazing capacity. Once grazing capacity is determined, animal numbers may still need to be changed often, as dictated by weather, market, and other conditions. Adjustments in stocking rates are best guided by animal management requirements and the suggested minimum residual dry matter levels (Clawson et al. 1982). Allowable limits of residual dry matter are best measured or estimated on areas with slopes less than 25% and with less than 50% canopy cover. Suggested lower limits of residual dry matter (RDM) are listed on the scorecards.

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Estimated Grazing Capacity Scorecards

Table 1. Southern California Zone (less than 10" precipitation)

Canopy Cover (percent)	Slope Classes (percent) < 10%	10%-25%	25%-40%	> 40%
	AUM/Acre			
0% to 25%	0.7	0.4	0.3	0.1
25% to 50%	0.4	0.3	0.2	0.1
50% to 75%	0.2	0.1	0.0	0.0
75% to 100%	0.1	0.0	0.0	0.0
	RDM lb/acre			
	200	250	300	350

Table 2. Central Coast and Central Valley Foothills Zone (10" to 40" precipitation)

Canopy Cover (percent)	Slope Classes (percent) < 10%	10%-25%	25%-40%	> 40%
	AUM/acre			
0% to 25%	2.0	0.8	0.5	0.3
25% to 50%	1.5	0.6	0.4	0.2
50% to 75%	1.0	0.4	0.3	0.1
75% to 100%	0.5	0.2	0.2	0.1
	RDM lb/acre			
	400	600	800	800

Table 3. Northern California Zone (greater than 40" precipitation)

Canopy Cover (percent)	Slope Classes (percent) < 10%	10%-25%	25%-40%	> 40%
	AUM/acre			
0% to 25%	3.5	1.3	0.8	0.5
25% to 50%	2.8	1.0	0.6	0.3
50% to 75%	1.8	0.7	0.5	0.2
75% to 100%	0.9	0.3	0.2	0.1
	RDM lb/acre			
	750	1000	1250	1250

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Yellow Starthistle Control

Craig D. Thomsen, Marya E. Robbins, and Stephanie Larson

Yellow starthistle, *Centaurea solstitialis,* is a plant of Old World origin that probably arrived in California in the mid-1800s as a contaminant in alfalfa seed. Since its arrival it has steadily spread and now inhabits nearly 8 million acres statewide. Yellow starthistle is one of California's worst noxious weeds, infesting rangelands, pastures, hayfields, orchards, vineyards, roadsides, canal banks, and parklands. It has many traits that make it a successful weed including: 1) a large seed output, 2) seeds that germinate over a long period of time, 3) a deep taproot, 4) late spring and summer growth, 5) an ability to quickly regrow after mowing or grazing, 6) and spines that discourage grazing in the reproductive stage.

Yellow Starthistle in Horse Pastures

Yellow starthistle represents a special problem in horse pastures. When eaten in sufficient quantities it can lead to a fatal nervous symptom called "chewing disease." The nature of the disease is such that the plant may be ingested over a period of years before any symptoms are apparent, and at that point it is irreversible. According to studies by Cordy (1978), the symptoms set in when the horse has eaten from 86% to 200% of its body weight. Fifty-nine percent of the fatalities have been reported during October and November and twenty-two percent in June and July. These two peak periods correspond to the beginning and end of the growth season for most annual plants. Yellow starthistle's strong presence when other pasture and range vegetation is scant probably results in heavier consumption by horses during these periods. While many owners keep their horses in starthistle-infested fields without incident, there is a risk involved, and it is best to eliminate or reduce starthistle to avoid any problems.

Life Cycle and Plant Description

Yellow starthistle has a very long life cycle for an annual plant. Germination is initiated by autumn rains, but plants mature long after most other annuals have completed their life cycle, sometimes not completing their life-cycle until late summer or fall. In addition, successive germination occurs long into the growing season.

The seedling stage is the most difficult time to identify the plants. A good way to recognize them is to first locate seedings under older starthistle skeletons that remain in the field from the previous years growth. The winter and spring rosettes produce many deeply-

University of California and the United States Department of Agriculture cooperating.

lobed leaves. Although there is variability in the size and lobing pattern of the rosette leaves, a good diagnostic character is the large terminal, triangular lobe at the tip of each leaf. In general, the rosettes tend to grow close to the ground in open places but assume an upright habit when there is an abundance of neighboring vegetation.

During May and June the plant "bolts" and sends up stalks, which give rise to the flower heads. The mature plant reaches a height of one to three feet. The grey-green to bluish-green stems of the mature plant are widely branched, and the entire plant is covered with soft, appressed hairs. Rigid spines project from the bracts that surround the bright yellow flowers.

The seed development stage can be recognized by the absence of the bright yellow pigment that characterize the younger flowers. Two types of seed are produced. The light-colored disk (central portion of the flowerhead) seeds contain short bristly hairs and are dispersed quickly after maturity. The outer seeds lack hairs and persist for months, remaining in the flower heads until harsh weather or some other disturbance breaks them up. The number of seeds produced by individual plants vary widely according to conditions and genetic factors. In studies of starthistle populations from Hopland, Woodland, and Concord, Maddox (1981) reported a range from about 700 to 10,000 seeds per plant. Thomsen and Williams (1990) have found that when densities are high and plants are crowded, small individuals may produce fewer than 100 seeds but larger plants produce seed numbers in the range that Maddox reported. Occasionally yellow starthistle assumes a biennial habit, and seed production is much greater. Plants were observed that had been sprayed with an herbicide while in the bolting stage. The plants died back but grew vigorously the following season and produced over 170,000 seeds per plant! Seedling densities in sites heavily infested with starthistle reflect the large number of seeds produced. Mean values for seedling data collected on research plots at the UC Agronomy Farm on land heavily infested with starthistle were 1,000 per square meter and 3,400 per square meter at a Colusa County ranch.

Nine other growth stages have been identified from emergence to senescence (Figure 1, modified from Maddox, 1981). Close attention to these various stages is important when planning and implementing a control program.

SEASONAL DEVELOPMENT OF YELLOW STARTHISTLE IN NORTHERN CALIFORNIA

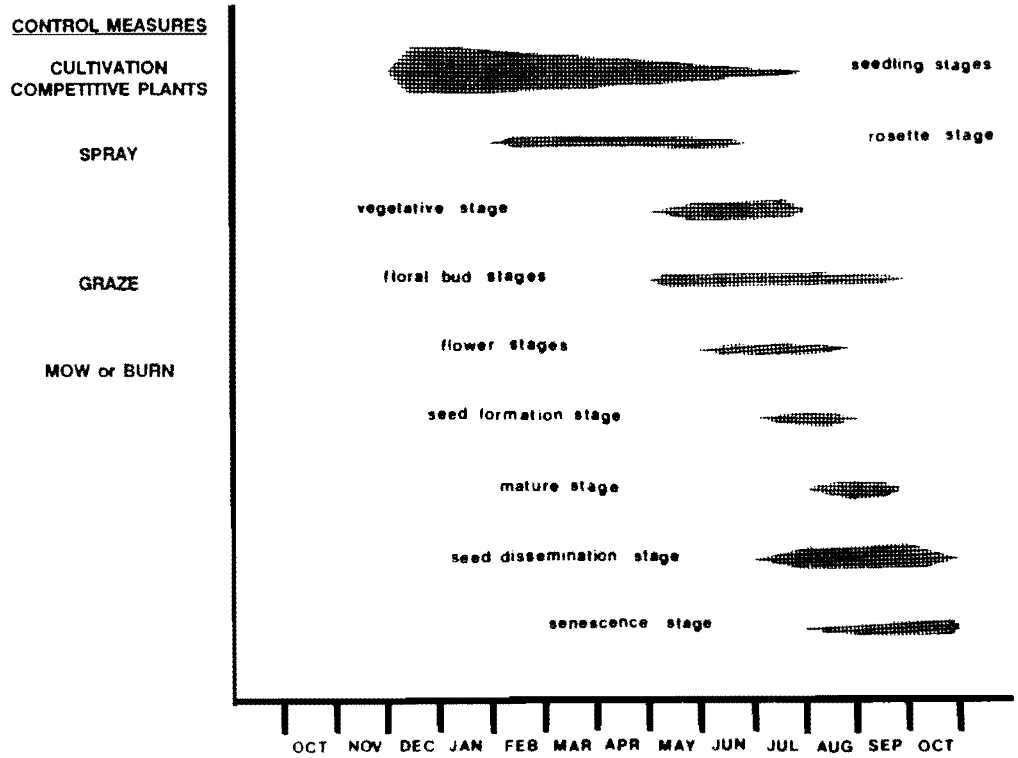

FIG. 1

AFTER MADDOX, (1981)

Control Considerations

There is no simple recipe for controlling yellow starthistle, and any method requires a systematic and persistent effort that may take several years or more. The approach that is taken will depend upon such factors as the size of infestation, plant density, location, equipment available, and planned use for the site. Control methods are most effective when used in combination. Regardless of the control method used, monitoring and follow-up methods will be necessary. Timing your control efforts to various stages of plant growth is essential. Figure 1 lists some control measures placed according to stage of starthistle growth. Some of these can be used over a wider period, but all of them should occur before seed production. Be aware of what plants will replace starthistle if the control program is successful as well as other changes that will occur in the ecosystem from control activities. It may be necessary to seed in desirable species to help prevent reinvasion by starthistle or other unwanted resident plants.

When planning any control program determine whether you're aiming to **eradicate, manage**, or **contain** yellow starthistle. Eradicating means to eliminate from the site and requires that seed production is halted and the seed reservoir in the soil from previous years is depleted or managed in a way so new seedlings don't emerge. When infestations are large, eradication will not be possible, but managing dense stands to tolerable levels may be. Often, the main concern with yellow starthistle is the spiny canopies that persist through summer and fall, and reducing them on an annual basis may suffice.

Containment is done by delineating boundaries around large infestations and concentrating control efforts on the smaller occurrences that exist outside of the contained areas. By controlling isolated plants or small patches that are the "pioneers," the larger infestation is contained and further weed spread is prevented. As information and experience is gained from controlling small occurrences, better decisions can be made about whether larger areas can also be successfully controlled.

Control Methods

There are five categories of control including **mechanical** (tillage, mowing, or grubbing), **fire**, **chemical** (herbicides), **biological** (insects, plant competition, and livestock grazing), and **preventative**. The various methods discussed below are based on established principles of weed control, anecdotal information, and research. Research is incomplete, but studies are underway to fill some of the information gaps.

Mechanical

Cultivation with appropriate implements as the seedlings emerge in the fall is an excellent means of removing young plants, but expect more plants to germinate with subsequent rains. On sites where irrigation is available, infested areas can be pre-irrigated prior to autumn rains and then disked to remove germinating seedlings. If this sequence is repeated much progress can be made in reducing the seed bank. Cultivation in the spring will remove most starthistle for that season but the degree of control will vary according to local conditions.

Hand-weeding or "grubbing" with a hoe or a weed-eater to control yellow starthistle in small areas should not be overlooked as an important part of any integrated weed control program. The easiest time for this is during the seedling or early rosette stages before the taproot has become well-developed. As the plant develops, its potential to regrow from the taproot is increased, and the upper portion of the taproot will need to be dislodged. Periodically monitor the site for more germination or regrowth.

Mowing is a useful method in managing yellow starthistle provided it is well-timed and repeated as necessary. Although no replicated studies have been done, preliminary studies indicate that when starthistle is mowed during the early flowering stage regrowth is minimized. Mowing at this stage removes the aerial portion of the plants after much of their root reserves has gone into producing flowers; therefore, less reserve is available for regrowth. Under some conditions, this single-event mowing may be sufficient, but plants should be monitored for regrowth and mowed again if significant growth and flowering occurs. When mowed at earlier stages, regrowth should be expected and several additional mowings will be necessary.

All mowing should be done prior to seed production. As mentioned previously, flower pigmentation is a good way to monitor whether seed development has commenced, but if in doubt open a flower. If the flowers are bright yellow and have not faded, seed production has yet to occur. Mowing after seeds have been produced removes the hedge-like canopies but does not diminish the seed bank and may aid in seed dispersal. In general, mowing will be most effective when soil moisture is low and no watering or rainfall follows the mowing.

Prescribed Burns

In some situations prescribed burns may be an appropriate management tool. The best time to burn is probably the same stage recommended for mowing.

Since starthistle is still green during this period, there must be enough dry biomass from other annual plants to carry a fire. Burning permits are available through the California Department of Forestry (CDF)

Chemical

There are many types of herbicides available, most requiring a permit from your County Agricultural Commissioner. If you are unfamiliar with herbicide use, we recommend Cooperative Extension publication, **Selective Chemical Weed Control** for specific information, or contacting your local Pest Control Advisor. Read and follow precautions on the label of any herbicide carefully before use. Herbicides should be used with an understanding that they are usually not a "one-shot" affair, particularly on large areas with dense stands of starthistle. Most studies have shown that repeated applications are necessary. Pay close attention to successive germination because starthistle will likely reappear.

Selective herbicides such as 2,4-D will help control yellow starthistle but leave grasses unaffected. However, they will also provide partial control of legumes, and other broad-leaved plants that may be useful to the ecosystem or production goals. If grazing is planned after spraying, a 30-day period following the application is necessary before resuming animal use.

Non-selective herbicides, like Roundup, are effective for spot treatments. However, since this kills nearly all other vegetation, treatment with Roundup is not usually suited for use over large areas.

Post-emergent herbicides are best applied in late winter through spring, when temperatures are warm, soil moisture is high, and plants are actively growing in the late seedling or rosette stage. Young seedlings are killed by herbicides but new plants will germinate with subsequent rains, so it is best to wait until early spring to reduce the likelihood of more germination. In studies conducted on a northern California ranch by Thomsen, et al. (1989), a 30 by 840 foot strip sprayed with 2,4-D was superimposed over replicated grazing treatments. Plants were sprayed in February when starthistle was in the early rosette stage. Reductions in plant densities were measured, but nearly six inches of rainfall during April-June boosted the surviving starthistle and many portions of the sprayed strip were so dense with starthistle that walking through was difficult. At another site where a similar strip (30 X 585 feet) was sprayed for two consecutive years and then left unsprayed the third year, starthistle was greatly reduced during the years of spraying but flourished the third year and produced flowerhead densities of nearly 450 per square meter. At approximately 35 seeds/head an estimated 15,750 seeds were disseminated per square meter.

Combining Chemical, Cultivation, and Plant Competition

Yellow starthistle is not usually found on heavily cropped land where there is frequent cultivation and herbicides are used that prevent plants from ever reaching maturity. Consequently, seed production does not occur and seeds germinating from the seed bank are routinely eliminated.

Dr. Tom Lanini, UC Extension Weed Ecologist, is currently evaluating Telar, a pre-emergent selective herbicide that persists up to two years. The aim of the research is to use Telar in combination with native perennial grasses to suppress yellow starthistle and other weeds that occur in drainage ditches, along roadsides, and borders of agricultural lands in Yolo County. Dr. John Anderson, Veterinarian, UC Primate Center, and one of the collaborators on this project views this as a means to not only control weeds, but also to create wildlife habitat for quail and pheasant, improve the esthetics of the rural landscape, integrate biological diversity onto agricultural lands, and reduce the $40,000 a year ($100.00 per mile) spent on roadside weed control in Yolo County (Bugg, et al. 1991).

Small Pasture Conversion

When dryland pasture is converted to a well-managed irrigated pasture, yellow starthistle becomes much less prominent and is sometimes eliminated entirely (Bryant, per. comm.). When infestations are severe, it is recommended to plant oats the first year and wait until good starthistle control is obtained before putting in a permanent pasture mix. Before planting, pre-irrigate and cultivate out starthistle seedlings to remove plants and draw down the seed bank. Repeat this step if possible. A good stand of oats provides a measure of competition against yellow starthistle, yet fields should be closely monitored and surviving plants should be controlled as necessary. If grazing is deferred, then the oats can be cut, baled, and utilized later for grazing. Within two weeks, the regrowth from surviving yellow starthistle plants will be visible and appropriate action to remove remaining plants can be taken.

The permanent pasture mix is best seeded after a substantial portion of the seedbank has been eliminated. This should result in better establishment because competition from starthistle will be less. When planting permanent pasture, seeding as much as twice the recommended seeding rate on smaller acreages can help to further crowd out yellow starthistle. The "no-till" drill allows seeding without turning up the soil and helps keep deeply buried seeds from germinating. If herbicide use is planned to control yellow starthistle after the pasture mix is sown, then a seed mix without legumes is recommended. As indicated, selective herbicides used for yellow starthistle will also reduce medics and clovers.

Another approach that has been used with some success according to Bob Roan (per comm.) of SCS is fall seeding of infested pastures with Lana vetch. Roan reported that yellow starthistle was suppressed by the aggressive, sprawling growth of the vetch, and the starthistle that survived was thin and weak.

Biological/Grazing

Insects to control yellow starthistle are currently being evaluated in the field to determine their effectiveness in controlling starthistle populations. Releases have been made and some appear promising, but no reductions in plant stature, density, or seed production have been measured. Individuals interested in biological control programs should consult their local agricultural commissioner's office or contact Dr. Charles Turner, Biological Control Laboratory, USDA-ARS, Albany, California (415) 559-5975.

Nutritional studies have shown that yellow starthistle is an acceptable component of a ruminant's diet. Well-timed controlled grazing with cattle (before plants produce spines) has been demonstrated to be an effective method for managing large stands of yellow starthistle in annual rangeland (Thomsen et a1. 1989, 1990). For three consecutive years, intensive cattle grazing reduced plant densities and seed production in the dense starthistle stands under study. Spiny canopies persisted through summer and fall in the ungrazed paddocks but were greatly diminished in the grazed areas. Cattle will readily graze yellow starthistle at all stages before it produces spines but effective management requires that grazing occurs during the stem elongation and floral bud stages, and is repeated several times to remove the regrowth. Most defoliated plants recover quickly and animals should be put back about two weeks later to regraze the plants. The late-season grazing that targeted starthistle occurred after annual grasses, legumes, and most other resident annuals had completed their life cycle and produced seeds. Moreover, appreciable amounts of plant residue remained on the soil surface and favorable conditions for other plants were maintained.

In this research intensive grazing management (high stocking densities with short grazing periods facilitated by portable electric fencing) was used and highly uniform defoliation of starthistle was obtained. However, observations from other sites where continuous low-density grazing is practiced indicate that if cattle are present during the late stages of growth and grazing pressure is maintained, animals utilize the plant and also suppress it. On the other hand, if grazing occurs when starthistle is in the rosette stage but is not continued during bolting yellow starthistle tends to be favored. This was demonstrated by experiments conducted at the UC Agronomy Farm using sheep (Thomsen, Williams and George 1990). In addition to grazing yellow starthistle, neighboring plants are defoliated and the competition they provide is eliminated. Yellow starthistle's ability to regrow following defoliation surpasses most, if not all other annual plants on California ranges

Preventative

Preventative weed control measures generally refer to doing what is necessary to prevent the introduction of new weed species to a specific area. As in containment programs, this includes detection and control of "pioneer" plants before they go to seed along roadsides, fields, pastures, etc. and develop into large infestations. Because spot occurrences and small colonies seem harmless, the tendency is to overlook them; however, this is the way most large infestations begin. Even though yellow starthistle is widespread, there are still many portions of the state where it has yet to invade but is well-adapted.

Conclusion

Since 1958 it has been estimated that yellow starthistle infested land has increased from 1.2 to 7.9 million acres, an increase of 640% (Maddox 1985). Yellow starthistle will continue to increase statewide and will be particularly prominent in years with abundant late-season rainfall.

Ongoing research efforts on yellow starthistle control includes seed bank studies, mowing, and goat grazing at the UC Davis Agronomy Farm; seed bank studies at Sierra Field Station; cattle grazing at a Colusa County ranch; and the use of native grasses in combination with herbicides along roadsides in Yolo County.

We thank Drs. Bill Williams and Tom Lanini for their helpful reviews of this document.

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Department of Agronomy and Range Science
UNIVERSITY OF CALIFORNIA, DAVIS

RANGE SCIENCE REPORT

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No. 30 June 1991

Yellow Starthistle Control

Craig D. Thomsen, Marya E. Robbins, and Stephanie Larson

Yellow starthistle, *Centaurea solstitialis,* is a plant of Old World origin that probably arrived in California in the mid-1800s as a contaminant in alfalfa seed. Since its arrival it has steadily spread and now inhabits nearly 8 million acres statewide. Yellow starthistle is one of California's worst noxious weeds, infesting rangelands, pastures, hayfields, orchards, vineyards, roadsides, canal banks, and parklands. It has many traits that make it a successful weed including: 1) a large seed output, 2) seeds that germinate over a long period of time, 3) a deep taproot, 4) late spring and summer growth, 5) an ability to quickly regrow after mowing or grazing, 6) and spines that discourage grazing in the reproductive stage.

Yellow Starthistle in Horse Pastures

Yellow starthistle represents a special problem in horse pastures. When eaten in sufficient quantities it can lead to a fatal nervous symptom called "chewing disease." The nature of the disease is such that the plant may be ingested over a period of years before any symptoms are apparent, and at that point it is irreversible. According to studies by Cordy (1978), the symptoms set in when the horse has eaten from 86% to 200% of its body weight. Fifty-nine percent of the fatalities have been reported during October and November and twenty-two percent in June and July. These two peak periods correspond to the beginning and end of the growth season for most annual plants. Yellow starthistle's strong presence when other pasture and range vegetation is scant probably results in heavier consumption by horses during these periods. While many owners keep their horses in starthistle-infested fields without incident, there is a risk involved, and it is best to eliminate or reduce starthistle to avoid any problems.

Life Cycle and Plant Description

Yellow starthistle has a very long life cycle for an annual plant. Germination is initiated by autumn rains, but plants mature long after most other annuals have completed their life cycle, sometimes not completing their life-cycle until late summer or fall. In addition, successive germination occurs long into the growing season.

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RANGE SCIENCE REPORT

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Ecology and Management of Tarweed

G.K. Perrier, W.A. Williams, J.W. Menke and M.R. George

Yellow tarweed, *Holocarpha virgata*, is a native plant that is well adapted to the hot dry summers in the Central Valley of California and the surrounding foothills. Tarweed is in the Composite family. It was first classified as *Hemizonia virgata*.

In the summer tarweed's aromatic summer growth is sometimes tall and sticky. It is not palatable to livestock, hides forage needed by livestock, and coats the faces and legs of livestock with a tarry resin.

With the arrival of Europeans, California's grasslands changed dramatically. Annual grasses and forbs from the Mediterranean area were introduced both accidentally and intentionally. These species were shorter-lived and shallower-rooted than the perennial grass that they replaced. Growing numbers of domestic livestock greatly increased the grazing pressure on the range, resulting in less soil moisture use by plants. Also, the summer fires that had swept through the perennial grasslands were controlled. These changes undoubtedly favored the spread of tarweed.

Control

Reducing Tarweed Density

These techniques can greatly reduce a population of tarweed, leaving very few plants to flower and set seed. However, the timing of these activities is critical.

Mechanical: Mowing to 4" in May reduced tarweed by 20%, mowing in July reduced tarweed by 90%, whereas mowing in late August eliminated all but a few prostrate plants. Density in the year following late summer mowing was reduced by 90%.

Chemical: University of California researchers, using 1.5 lb/acre of a low volatile ester of 2,4-D, found that tarweed was affected much more by the herbicide treatment before elongation (April 21) than after elongation (July 14). Because legal restrictions on herbicides are constantly changing, you should contact your Ag. Commissioner before using any chemical control method.

Seedbank: One of the major obstacles to mechanical or chemical removal of tarweed is the seedbank of hard ray achenes that exists on sites. After five years of summer mowing, tarweed densities were about 10% of those in unmowed plots. To be successful, the use of these methods must be long-term (over five years) to totally eliminate tarweed, otherwise the pasture will be reinfested once the eradication project ends.

Continued on next page.

Phenology, Growth, and Reproduction

Tarweed germination starts in the fall with the first rains and continues into April. Other summer annuals such as turkey mullein (*Eremocarpus setigens*) and vinegar weed (*Trichostema lanceolatum*) germinate in the spring and appear to be restricted to open areas with low vegetative cover, thus avoiding competition with the winter annuals.

By the end of winter, the tarweed plant has developed a deep taproot and about a dozen broad leaves in a rosette. Roots of tarweed go deeper than most of the winter annual grasses, reducing competition with them for soil nutrients and moisture. Penetration rates in sand of over 1.5 inches per day have been observed. From late spring until early summer the shoots elongate and branch out with bract-like leaves on woody stems that stand 1 to 2 feet tall.

In August and September tarweed produces composite heads that have 3 to 5 ray flowers and 3 to 12 disk flowers. The ray flower is incomplete, having only a carpel, but the disk flower also has anthers that produce abundant pollen, an important food source for honeybees. The ray and disk achenes (fruiting structure containing a seed left after the flower dries) mature by the end of September. Achene dispersal is caused by rain, wind, and wildlife and continues into the winter. The achenes, which have over 20% crude protein, are eaten by ground squirrels.

The ray achenes are quite different in appearance, hardness, and the vigor of resulting seedlings, but there appears to be no morphological difference between the plants they produce. The ray achene is 3 mm long, ovate-shaped, and extremely hard. In laboratory tests no germination was achieved without scarification. The factors causing ray achenes to germinate in the field are unknown. Tarweed produces at least 5 times as many fertile ray achenes as fertile disk achenes.

The disk achene is 4 mm long and lanceolate shaped. Newly collected disk achenes with filled endosperms have 100% germination without any pretreatment, but less than one-fourth of the disk achenes are filled. Most of the germination in the fall is from disk achenes.

Achene dispersal and plant senescence starts at the end of October. By the end of spring only the woody stems and thicker branches remain, and they stand until the following rainy season.

Livestock use tarweed in winter and early spring while it is young and succulent. Use decreases rapidly as it increases in height and resin covering. It is hardly grazed at all at maturity when covered with resinous exudate, although it is still an important source of protein and moisture for ground squirrels. Summer annuals are often the only actively growing green plants, relatively high in protein, available in the summer on annual range. To discourage herbivory, summer annuals have apparently evolved mechanisms such as spines, aromatic compounds in vinegar weed (*Trichostema lanceolatum*), and aromatic resins as in tarweed. Few animals are able to feed on these plants in the summer.

Continued from previous page.

Depleting Soil Moisture

Fertilization: Nitrogen fertilization increases the vigor and productivity of tarweed's competitors, making them better able to deplete soil moisture that supports tarweed survival and growth in the summer. The fertilizer should be applied in the fall to ensure that winter annuals utilize it efficiently. However, it is doubtful whether the large amounts of nitrogen fertilizer required annually to reduce tarweed density effectively (107 lb/a) would be economical if applied to rangelands.

Annual legumes: Nitrogen fixation by annual legumes increases forage production and reduces soil moisture available to tarweed. Rose clover (*Trifolium hirtum*) fertilized with single superphosphate has been shown to reduce tarweed. Lana vetch, subterranean clover, and the annual medics should have the same affect.

Perennial grasses: Although no studies have demonstrated a reduction in tarweed, established perennial grass seedings should deplete soil moisture, making it unavailable to tarweed.

Competition

Tarweed competes with winter annuals by diminishing soil moisture in late spring. Because tarweed germinates in the fall and grows in close association with dense stands of winter annuals, there is probably also some competition for light and nutrients during the growing season, but the degree of competition is unknown.

The occurrence of tarweed in the early successional stages of the annual grassland-type indicates that it is more compatible with the less productive species commonly found in these stages, thus tarweed has been designated an "invader" species. The shallow-rooted, short statured, early maturing alien annual grasses use less light and water than the late successional perennial grasses or taller annual grasses. This results in a surplus of moisture that tarweed is able to utilize.

Because tarweed relies on stored soil moisture for summer growth, it is most competitive on deep fine textured soils. Tarweed is distributed widely over the range but is more common in swales, and tarweed often dominates the better forage-producing sites.

Annual variations in climate—mainly rainfall and temperature—result in large year-to-year differences in the composition of the California annual grasslands. Annual grasses are dominant in some years, and annual forbs or annual legumes in other years. The amount of competition between tarweed and these winter annuals is less in grass dominant years and greater in forb-dominant years. The nitrogen-fixing ability of annual legumes tends to increase soil fertility, which increases forage production and water use and therefore reduces tarweed densities.

Instead of being a highly competitive invader like some alien annual grasses, tarweed seems to have been able to invade the annual grassland by taking advantage of underused resources of moisture, nutrients, and light.

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Department of Agronomy and Range Science
UNIVERSITY OF CALIFORNIA, DAVIS

RANGE SCIENCE REPORT

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No. 32 | **January 1992**

Ecology and Management of Medusahead

Melvin R. George

Medusahead is a winter annual native to the Mediterranean region of Eurasia. It is one of the primary range weeds in the western United States. It is a serious threat to rangelands with sparse native plant communities and more complex communities degraded to a low seral state. Medusahead is an aggressive competitor with other plants including other annuals in California's foothill rangelands. A low-value forage species for livestock and wildlife, it has been estimated that the carrying capacity of rangeland for domestic livestock has been reduced by 75 percent after medusahead invasion.

Medusahead was introduced into the United States from the Mediterranean region of Eurasia, where it consists of three geographically and morphologically distinct taxa. It was originally mistakenly classified as *Elymus caput-medusae* which originates from Siberia. Another species, *Taeniatherum crinitum,* grows in North Africa and in the southern Balkans through the Middle East to Soviet Central Asia. The third, *Taeniatherum asperum,* our western American weed, originally was found from Hungary through Ukraine to Tadzhikistan.

The late 1800s is believed to be the approximate time of introduction of medusahead into the United States. The plant probably was brought to North America through dispersal of seed by imported animals. The first known specimen submitted to the University of California herbarium was collected near Roseburg, Oregon in 1887. In 1901, it was recorded from Steptoe Butte in eastern Washington, and in 1908, near Los Gatos, California.

It has spread from its original infestation near Roseburg, Oregon to the Palouse region of Washington and Idaho, to southern Idaho and the

Control

Reducing Medusahead Density

Fire: A slow hot fire after medusahead seeds have ripened but before they drop will reduce medusahead up to 90 percent the following year. Grazing should be deferred to build up fuel. A properly timed burn for medusahead is when the other vegetation has dried and dropped its seeds.

Chemical: Herbicides applied in March and April will reduce medusahead. Check with your Ag. Commissioner to determine which herbicides are registered for this use.

Grazing Management: Intensive grazing during the growing season will reduce medusahead in about two years. Time controlled grazing reduced medusahead from 45 percent of the cover to less than 10 percent in southern Tehama County. Stock densities of six 500-700 lb. stocker calves per acre were used on this Tehama County ranch.

Mechanical: Disking and plowing before seed set can reduce medusahead by 90 percent or more.

Increasing Density of Competition

Fertilization: Nitrogen fertilization can reduce medusahead by increasing competition from other grasses and forbs, by increasing palatability, and by depleting soil moisture.

Annual legumes: Before reducing medusahead some thought must be given to what will replace it. Annual legume (subterranean and rose clover and lana vetch) seedings following one of the above control methods will replace medusahead with a very desirable plant. Left unseeded Mother Nature will be free to choose the replacement plant. If you are lucky she will choose filaree. But she could just as well choose a less desirable plant.

Perennial grasses: Seeding of perennial grasses such as perlagrass or Berber orchardgrass would be an alternative if grazing management is changed to time controlled grazing. Perennial grasses are unlikely to survive continuous grazing. Success with perennial grass seedings is variable and highly dependent on rainfall patterns.

northern half of California where it has been an invader since the early 1900s.

Medusahead probably has not reached its ecological limit. The plant successfully competes and overlaps both in area and in local habitat ecology with two other exotic, annual range invaders—soft chess brome *(Bromus mollis)* in California and southern Oregon and cheatgrass *(Bromus tectorum)*. If the requirements of medusahead completely overlap those of cheatgrass it could spread widely in the Great Basin.

Environmental Factors

Medusahead grows over a wide range of climatic conditions. Annual precipitation on medusahead sites throughout the four Western States ranges from 10 inches to 40 inches. Medusahead grows where precipitation occurs during fall, winter, and spring. Distribution of precipitation is more significant than total precipitation in meeting the species moisture requirements.

Medusahead grows where extended periods of great cold are lacking. Moreover, some of these climates are extremely hot. Medusahead requires a cold treatment and possibly light stimulus after germination for seed formation to occur. In one study, successful seed formation occurred after exposing seedlings to nightly temperatures of 37°F for 14 days in the field. The seedlings matured in the greenhouse.

Soil conditions suitable for growth of medusahead are somewhat variable. Favorable environmental factors related to medusahead distribution are soils with a high clay content and well-developed profiles, and areas receiving run-off water from adjacent sites. Less susceptible to invasion are well-drained soils and those developed from rocks weathered to coarse-textured sands showing poorly developed profiles. Late maturity of the species in relation to other annual grasses and its subsequent requirements for high water-holding capacity clay soils are the accepted explanation for medusahead abundance on clay soils.

Growth Characteristics

Medusahead is able to compete effectively with desirable forage species because of the following growth characteristics: (1) rapid fall germination and root growth throughout the winter, (2) prolific seed production, and (3) accumulation of litter that decomposes slowly.

Medusahead seedling roots begin post-germination growth in the fall and grow all winter, thus effectively reducing available soil moisture to competitors. Medusahead also matures later than neighboring competitors because its root system remains functional for a longer period of time.

Medusahead is a highly prolific seed producer with germination rates of 98 percent. In dense stands, plant numbers ranged from 1,500 to 2,000 per square foot on valley bottom soils, and 500 plants per square foot on scablands. Average number of seeds per head for these two sites were 9 and 6, respectively.

Once medusahead becomes established it grows in dense stands, forming a mat of stems 2 to 5 inches thick. The high silica content of medusahead may be the reason it is slow to decompose. Evidence indicates that the dense litter cover is important in the competitive relationship with other annuals, because most neighboring competitors fail to grow under the accumulated thatch. Medusahead's litter also is an extreme fire hazard in the summer and ties up nutrients otherwise available for plant growth. However, it has been reported that the accumulation of slowly decomposing litter may safeguard soil from wind and water erosion.

Nutritional Characteristics

Moisture content, crude protein, crude fiber, and lignin contents of medusahead compare to other annual range species at similar growth stages (Table 1). However, ash content of medusahead was found to be greater than that of cheatgrass. The ash of medusahead contained approximately 72 to 89 percent silica and amounted to more than 10 percent of the dry weight of plant. The high silica content of medusahead is thought to be the basis for its harshness. The long barbed awns and sharp, hard seeds of the mature plant injure eyes and mouths of livestock.

Although numerous reports have indicated medusahead is unpalatable, other investigators have found heavy livestock grazing on immature plants in early spring. Range fertilization, especially with N, offers a possible way to improve the palatability of medusahead and to encourage its early use by grazing animals. An *in vitro* nutritive evaluation revealed that immature medusahead had a higher cellulose digestion value than a mixture of desirable annual range forage species.

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Table 1. Nutritional value of medusahead compared to cheatgrass, softchess and filaree.

		Leaf	Heading	Flowering	Dough	Mature	
						Early	Late
		% Moisture					
1.	Medusahead	66.8	62.7	50.3	34.9	--	--
2.	Cheatgrass	--	64.6	49.0	30.3	8.2	--
3.	Soft chess	--	--	--	--	--	--
4.	Filaree	--	--	--	--	--	--
		% Crude Protein					
1.	Medusahead	10.4	8.8	6.8	6.5	7.3	--
2.	Cheatgrass	--	8.0	8.8	7.1	4.6	4.7
3.	Soft chess	14.9	12.5	11.0	7.8	6.3	2.9
4.	Filaree	25.0	20.8	16.3	11.2	10.0	--
		% Fat					
1.	Medusahead	2.6	2.3	1.8	1.6	1.0	--
2.	Cheatgrass	--	1.5	2.0	1.8	1.3	1.2
		% Fiber					
1.	Medusahead	26.8	27.4	31.2	28.1	30.5	--
2.	Cheatgrass	--	31.3	24.5	27.2	35.6	39.6
3.	Soft chess	25.0	25.0	30.8	28.0	31.5	39.0
4.	Filaree	16.0	16.0	16.8	19.0	26.5	--
		% Lignin					
1.	Medusahead	6.1	9.7	8.6	10.0	7.9	--
2.	Cheatgrass	--	8.4	8.5	9.7	11.2	11.4
		% Ash					
1.	Medusahead	13.9	13.7	12.8	14.7	14.5	--
2.	Cheatgrass	--	8.1	8.7	8.7	9.9	8.0
3.	Filaree	14.0	15.0	14.5	11.4	12.0	--
		% Silica					
1.	Medusahead	11.3	--	--	--	--	--
2.	Cheatgrass	--	4.4	--	--	--	--
3.	Soft chess	2.3	3.5	--	--	--	3.8
4.	Filaree	.5	.7	--	--	3.3	--

Department of Agronomy and Range Science
UNIVERSITY OF CALIFORNIA, DAVIS

RANGE SCIENCE REPORT

Agricultural Experiment Station
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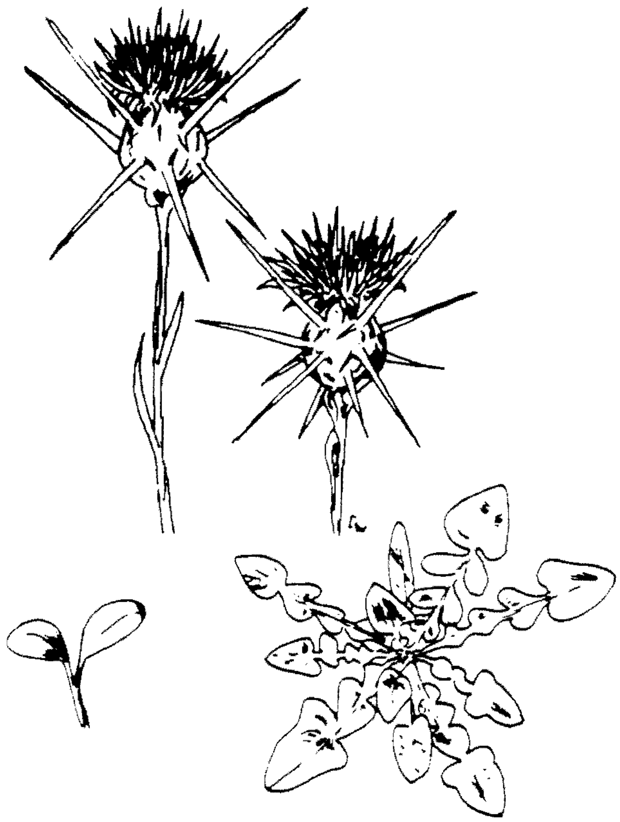
Yellow Starthistle Control

C.D. Thomsen, W.A. Williams, M. Vayssieres, and F.L. Bell

Yellow starthistle, *Centaurea solstitialis*, is a plant of Old World origin that probably arrived in California in the mid-1800s as a contaminant in alfalfa seed. Since its accidental introduction, it has steadily spread and now inhabits about 8 million acres statewide (Maddox and Mayfield 1985). It is one of California's worst noxious weeds, infesting parks and rangelands, pastures, hayfields, orchards, vineyards, roadsides, and irrigation banks. The presence and tenacity of starthistle on these lands has led to increased vegetation management costs and many inquiries on methods of control.



Life Cycle and Plant Description

Understanding yellow starthistle's biology is basic to developing a successful control program. Starthistle has a very long life cycle for an annual plant. Germination is initiated by autumn rains, but plants mature long after most other annuals have completed their life cycle, sometimes not completing their life cycle until the following fall or winter. The seedling stage is the most difficult time to identify the plants. One way is to locate seedlings under last year's skeletons. The winter and spring rosettes produce many deeply-lobed leaves. The size, number, and lobing pattern of the rosette leaves are variable, but a good diagnostic character is the large, triangular lobe at the tip of each leaf. In general, the rosettes tend to grow close to the ground in open places but they assume an upright habit at high densities.

During May and June the plant 'bolts' and sends up elongated stalks that produce the spiny flower heads. The grey- to bluish-green stems of the mature plant are ridged and widely branched, and the entire plant is covered with soft, appressed hairs. The bracts that surround the bright yellow flowers produce the characteristic rigid spines. The seed maturation stage can be recognized by the loss of the bright yellow pigment that characterizes the younger flowers. At this stage the seeds mature quickly. Two types of seed are produced. The lighter-colored seeds are located in the central (disk) portion of the flowerhead, contain short bristly hairs (pappus), and disperse quickly after maturity. Darker seeds occur in a circle around the disk seeds, usually lack hairs, and persist in the flowerhead until harsh weather or other disturbances break them up. After dispersal seeds become part of the soil's "seed bank" where they remain until conditions become favorable for germination, or are eliminated through natural means.

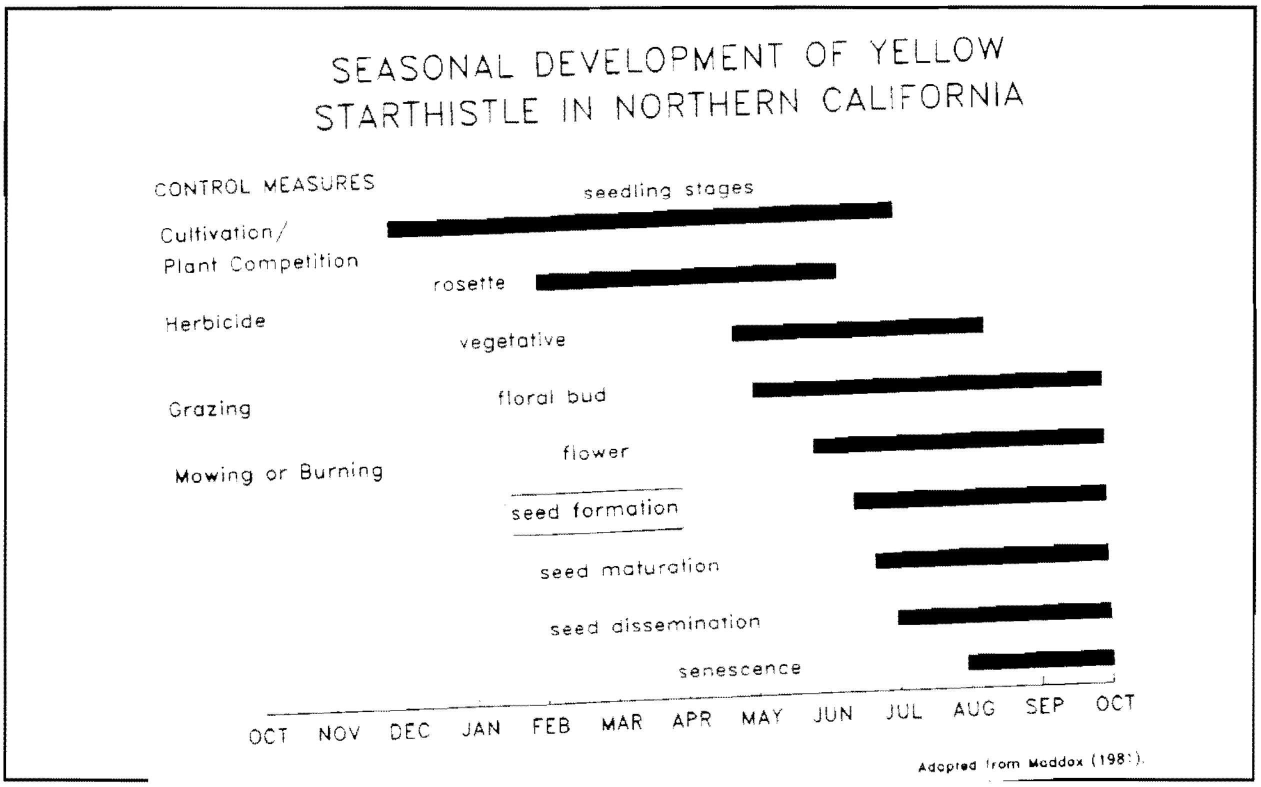
The number of seeds produced by individual plants varies widely according to environmental conditions and genetic factors. In a study of starthistle populations from Hopland, Woodland, and Concord, Maddox (1981) reported a range of 700 to 10,000 seeds per plant. Thomsen (unpublished data) followed an individual plant that had been sprayed with an herbicide during the bolting stage. The upper portion of the plant died back but regrew vigorously the next growing season from the taproot and produced an estimated 170,000 seeds.

Control Considerations

Controlling yellow starthistle on infested lands will require a systematic and persistent effort that may take many years. In many cases it will be an ongoing land management activity that will need to be continued on a more or less permanent basis. Various approaches can be taken, but the degree of control possible will depend on the size and density of the infestation, terrain, tools or equipment available, and planned use for the site.

When planning a control program one should decide if the aim is to **eradicate, manage,** or **contain** yellow starthistle. Eradication is the elimination of starthistle from the site, and requires that all seed production is halted and the seed bank in the soil from previous years is depleted. Eradication of large infestations is not practical but small infestations often can be successfully eliminated with diligence. Large infestations can usually be managed in ways that reduce starthistle to tolerable levels. Suitable management aims are to decrease plant densities, seed production, or plant height and canopy size, or use it as a feed resource for ruminants. Containment is attempted by delineating boundaries around large infestations and concentrating control efforts on the smaller patches that exist outside of the contained areas. By controlling isolated plants or small patches that are the "pioneers" of new infestations, the larger infestation is contained and the likelihood of invasion into new areas is reduced. As information and experience is gained from controlling small outlying infestations, better decisions can be made about whether larger areas can also be successfully controlled.

Timing control efforts to various stages of plant growth is essential. Figure 1 suggests the timing of some control measures according to specific stages of starthistle growth. Some measures can be used during several growth stages, but all of them should occur before seed set. The duration of life cycle stages depicted by the bars will vary considerably due to weather patterns, site differences, and genetic variation. Thus, on-site monitoring is necessary to determine exactly when a particular stage is occurring and control activities should be adjusted accordingly.



Control Methods

The methods of control include mechanical (tillage, mowing, and removal with hand tools), biological (insects, livestock grazing, and plant competition), fire, chemical, and prevention. In general the most effective control is achieved when two or more methods are used in combination. The methods discussed below are based on research, established principles of weed control, and anecdotal information. Research is incomplete, but studies are underway to fill some of the information gaps.

Mechanical Methods. Cultivation with appropriate tools as the seedlings emerge after autumn rains is an excellent means of removing young plants. On sites where irrigation is available, infested areas can be pre-irrigated prior to autumn rains and then disked to remove germinating seedlings. If cultivation is repeated after rains begin and a new flush of germinating seedlings has emerged, the seed bank can be reduced in a short time. When cultivation is done in the spring, plants will have well developed taproots and tillage should be deeper. Any tillage will also bring deeply buried seeds to the surface where they will have more favorable conditions for germination. If follow-up measures are not taken to also remove these seedlings, the infestation could get worse.

Mowing is a useful method for managing yellow starthistle stands, provided it is well-timed and repeated one to two times. Mowing will be most effective when soil moisture is low and no irrigation or rainfall follows. Under low soil moisture conditions a single mowing may be sufficient, but plants should be monitored for regrowth and mowed again if significant growth and flowering occurs. In most situations, one or two "follow-up" mowings will be necessary and should be done once flowering resumes, approximately four to six weeks later. Research at the UC Agronomy Farm demonstrated that mowing during the early flowering stage (before seed formation) reduced canopy size, seed production, and live plant density when compared to controls (unmowed) and plots mowed at earlier stages of development. Mowing too early appears to encourage its growth.

Ideally, all mowing should be done just prior to seed formation. Flower pigmentation is a good way to monitor whether seed development has commenced. When the flowers are bright yellow and have not begun fading, seed maturation has not occurred. If in doubt open a flower and check for mature seeds. Mowing after seeds have been produced removes the spiny canopies but does not diminish the seed bank and may aid in seed dispersal.

Manual weeding with hoes, weedeaters, or scythes is often a practical way to control small infestations or is useful as an adjunct to other methods. Hand-held equipment can be ideal for spot weeding plants that survived from other weed control activities.

Biological Control

Biological control involves the use of any biological organism such as insects, livestock grazing, and competitive plants that aid in starthistle suppression.

Insects

Several insects are being evaluated to determine their effectiveness in controlling starthistle populations. Field releases have been made throughout the state and some candidates appear promising, but additional time is needed to assess the long-term effects of these biocontrol agents.

Livestock Grazing

Controlled grazing has been demonstrated to be an effective method for managing large stands of yellow starthistle in annual grassland (Thomsen et al. 1993). Livestock will graze yellow starthistle before it becomes spiny, and studies have shown that it is an acceptable component of a **ruminant's** diet (Cordy 1978; Thomsen et al. 1989). Over a period of several years cattle, sheep, and goats were tested separately as biocontrol agents in densely infested grassland using intensive grazing management, i.e., high stocking densities and short grazing periods, timed to specific stages of starthistle development. Grazing while starthistle was in the rosette stage (March through April) did not suppress starthistle, but grazing during the bolting stage (May through June) reduced plant densities, height, and seed production. Grazing during the rosette stage favored yellow starthistle relative to other herbaceous vegetation. Along with yellow starthistle, neighboring plants were also defoliated, and the competition they provided was largely eliminated, since starthistle's ability to regrow following defoliation was much greater than the associated vegetation. When grazing was deferred until bolting, most other associated annual species had a chance to complete their life cycle and produce seed. Animals selectively grazed starthistle since it was still green and made use of it as a forage. Since most defoliated plants recovered quickly animals were brought back to the paddocks one to three times at about two week intervals. The actual number of grazings required for suppression varied according to rainfall patterns and soil moisture levels.

Grazing yellow starthistle should not be attempted with horses. Prolonged ingestion by horses (86-200% of the horse's body weight) can lead to a fatal nervous disease called equine nigropallidal encephalomalacia or "chewing disease" (Cordy 1978). Horses are the only animal known to be affected by this disease, most cases occurring during October/November or June/July. Donkeys and mules are probably susceptible, but there are no documented poisonings (Fowler, per. comm.). The majority of cases that have been reported are with horses that are under two years old.

Plant Competition

Establishing competitive plants such as well-adapted grasses, legumes, or other appropriate plant materials should be considered as part of any control program. If starthistle is controlled, but the ecological niche that it occupied remains unfilled, reinvasion by starthistle will be easier or invasion by another undesirable species is likely. In most cases, a two-step approach is effective with some initial control work done prior to seeding desirable plants as the first step. Using a no-till drill allows seeding without turning the soil, and helps to keep deeply buried starthistle seeds form germinating.

The choice of plant materials should reflect the site conditions, type of management required to establish and maintain the plantings, and planned use of the site. If a large and potentially costly seeding is planned, some initial on-site small scale plantings should be done to evaluate which plants are best suited for your site and whether they are truly competitive against starthistle under the prevailing land use.

Both annual and perennial grasses have potential to compete against starthistle but will be most effective when combined with other methods such as a broad-leaved herbicide application. The timing of rainfall has an important influence on the competitive outcome. If late-season rains (during April through June) recharge soil moisture, starthistle will be favored. Since most annuals complete their life cycle long before starthistle, there will often be sufficient soil moisture remaining to support starthistle growth. Also, starthistle has a long taproot that grows much deeper than annual grasses, so it can obtain soil resources even in dense stands of grass. Nevertheless, if grass stands are dense and tall, competition for space and for light can be a contributing factor that helps suppress starthistle.

Most dryland perennial grasses will require at least two years to gain enough stature to provide competition and dense stands are required. Once established, some perennial grasses do have late spring and summer growth similar to starthistle, and with their vigorous root systems there is greater potential to remove soil moisture that would otherwise be used by starthistle. However, perennial grasses should not be expected to suppress starthistle when grazed by livestock unless they are part of a well-managed irrigated pasture.

Vigorous stands of annual legumes have the potential to suppress yellow starthistle. Drake (per. comm.) reported that a dense stand of rose clover Trifolium hirtum eliminated yellow starthistle in a Siskiyou County trial. Lana vetch Vicia villosa ssp. varia, a vigorous and sprawling vetch that forms a dense spring canopy has been reported to suppress starthistle (Roan, per. comm.). Other annual legumes such as some subterranean clover cultivars, have also been observed to suppress starthistle, particularly when combined with mowing or grazing. Research to examine this more closely is underway, supported by UC IPM. To obtain competitive stands it is advisable to use high seeding rates and to make sure that the seeds are properly inoculated with the host-specific nitrogen-fixing bacteria, Rhizobia spp. Fertilization with phosphorus or sulphur should be considered on range soils since they are often deficient in these nutrients.

Prescribed Burns. In some situations prescribed burns may be an appropriate management tool. The best time to burn is probably the same as for mowing, when plants are in the early flowering stage just prior to seed formation. Since starthistle is still green during this period, there must be enough dry biomass from other annual plants to carry a fire. Research using prescribed fire is being conducted at Sugarloaf Ridge State Park in Sonoma County, but it is inconclusive at present. Prior to conducting a burn on small acreages your local fire station should be contacted to obtain information on safe practices, designated burn days, and permits. For large acreages, the California Department of Forestry and Fire Protection Vegetation Management Program may offer some assistance and cost-sharing, particularly when the burn is part of an overall vegetation management plan that reduces the fire hazard of an area.

Chemical Control. There are many types of herbicides available, most requiring a permit from your County Agricultural Commissioner. If you are not familiar with herbicide use, refer to UC

Cooperative Extension publication No. 1919, *Selective Chemical Weed Control* for specific information (Ashton 1987). Before using any chemical, carefully read and follow precautions on the label. Like any other control method, the use of herbicides must be properly timed and more than one application per growing season may be necessary. Interference from surrounding vegetation might prevent uniform application and leave some starthistle unaffected. Another complicating factor is the successive germination in starthistle populations that occurs long into the growing season, often associated with rainfall. When herbicides are applied before all germination has occurred new seedlings will emerge and develop into adult plants. Foliar-applied, postemergent herbicides are most effective when temperatures are warm, soil moisture is high, and plants are actively growing. Post-emergent herbicides are most effective in seedling and rosette stages prior to any bolting.

Non-selective herbicides, like glyphosate, are effective for spot treatments. However, since glyphosate kills nearly all other vegetation, treatment with this chemical is not usually suited for use over large areas. Broadleaved herbicides such as Banvel, triclopyr, or 2,4-D will help control yellow starthistle and leave grasses unaffected. Care should be taken because these materials will also partially control legumes and other broadleaf plants that may provide competition against starthistle or may be useful to the ecosystem by providing soil cover, forage, biological diversity, or wildlife habitat.

Broadcast spraying in an infested area is not always necessary. Starthistle stands are often patchy and known starthistle areas can be marked with irrigation flags months before spraying and then specifically targeted at the proper time. The grey starthistle skeletons with heads resembling Q-tips that remain in the winter from previous growth are also good markers for locating patches of new seedlings.

Prevention. Preventive weed control measures consist of preventing the introduction or spread of starthistle to uninfested areas. As in containment programs, this includes detection and control of "pioneer" plants before they go to seed along roadsides, in fields, pastures, etc., and develop into larger infestations. Because spot occurrences and small colonies seem harmless, the tendency is to overlook them; however, this is the way most large infestations begin. Even though yellow starthistle is widespread, there are still many areas where it is adapted but has yet to invade or fully establish.

Combining Control Methods

The most effective way to control yellow starthistle is to use a combination of control methods. There are many possible combinations that can be used and tailored according to the site. On arable land good control of starthistle is obtained by using a combination of cultivation, herbicides, irrigation, and crops. On pastures the use of adapted plant materials combined with controlled grazing, well-timed mowing, or herbicides can lead to reduced populations. Perennial grasses in combination with herbicides, cultivation, and burning have been used effectively to suppress starthistle in drainage ditches, along roadsides, and on the borders of agricultural lands (Brown, Bugg and Anderson 1993.). These researchers are using a phased approach to vegetation management of rural landscapes. They begin with intensive weed control to reduce the soil's seed bank. Grasses are planted and herbicides are still used but are reduced as the deep-rooted grasses become well-established and competitive. When herbicide use subsides, broad-leaf plants such as lupines, poppies, and other native forbs are incorporated into the system. The investigators view this not only as a means to control weeds, but also to create wildlife habitat for game and nongame species, improve the aesthetics of the rural landscape, integrate biological diversity onto agricultural lands, and reduce the $40,000 a year ($100.00 per mile) spent on roadside weed control in Yolo County (Anderson 1993; Bugg, et al., 1991). These are a few of the many possible combinations of methods for controlling starthistle. But regardless of what methods are used together, effective long-term control requires that 1) seed production is halted, 2) plants emerging from the seed bank are eliminated, and when possible that 3) other, more competitive plants be permanently established that fit in the ecological niche once filled by starthistle to prevent reinvasion and to suppress other undesirable species.

Discussion

Although yellow starthistle is a troublesome weed, it does have some useful properties. Starthistle is a valuable source of summer nectar for bees, and honey produced from it of premium quality. Yellow starthistle's early and late-season growth, palatability, and resilience make it a useful forage plant to ruminant animals before it becomes spiny. In nutritional studies, crude protein levels were recorded from as high as 28% in the rosette stage to 13% in the bolting stage. At one site during bolting starthistle was estimated to exceed 4,000 lbs/acre of dry matter in early June. Starthistle provides food and cover to wildlife, especially insects, small mammals, and some birds. As a colonizing species, it rapidly covers and helps stabilize unprotected soil.

But, despite these qualities, yellow starthistle remains a significant pest for many ranchers, landowners, and resource managers. Starthistle's invasiveness, stout spines, and hedge-like stands make controlling it a necessary task. Yellow starthistle will continue to increase statewide and is likely to be particularly prominent in years with abundant late-season rainfall.

Some ongoing research that we are involved with or aware of include timed mowing experiments and seed bank studies at the UC Davis Agronomy Farm; combining subterranean clover establishment with sheep grazing and mowing at the Bio-integral Resource Center near Winters; using perennial grasses along roadsides in Yolo County; prescribed burning and timed mowing at Sugarloaf State Park, Sonoma County; and biological control with insects and rusts at USDA-ARS, West Regional Research Center, Albany, California and at the Division of Biological Control, California Department of Food and Agriculture.

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RANGE SCIENCE REPORT

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Water Quality Effects of Rangeland Beef Cattle Excrement

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Causes of rangeland nonpoint source pollution are difficult to identify and quantify due to the complexity of watersheds. Concerns regarding rangeland cattle excrement on water quality has focused on nutrient and pathogen loading to water bodies. Pollutants from rangeland beef cattle excrement can effect water quality if the pollutants are directly deposited in the water body or if they are transported to the water body during storm events.

Nutrient and pathogen dynamics on rangeland watersheds are complex and vary through time and space. Often background levels of nutrients and pathogens are unknown. The spatial distribution of rangeland beef cattle excrement varies within and across watersheds. Cattle distribution is a function of topography, soils, vegetation, air temperature, water and supplement location, animal class, and fencing.

Some studies have attempted to compare cattle excrement deposited on the range to human waste deposited in a septic system (Lahonton 1985, DWR 1979). An important concept involved in this comparison is that humans import their food sources into a watershed while cattle predominantly consume forage produced in the watershed. Cattle export nutrients out of the watershed in the form of body mass. Beef calves that gain 2 to 2.5 pounds per day, of which 2.4% is nitrogen, 0.8 % is phosphorus (Azevedo and Stout 1974), illustrate the amount of nutrients that can be removed from grazed watersheds.

Nitrogen exported in tissues of domestic ungulates was estimated to be 17% of the N in ingested forage (Dean et al. 1975). Thus, assuming 70% moisture and 10% crude protein forage, for every ton of forage consumed about 1.6 pounds of nitrogen is removed from the system.

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To understand and quantify the fate of nitrogen on a watershed several things must be considered:

1.) Quality and quantity of the forage.
2.) Retention by the animal.
3.) Losses through volatilization and leaching of NH^{3}.
4.) Soil incorporation.
5.) Plant uptake.
6.) Spacial distribution of the feces and urine.
7.) Hydrology of the watershed.

Figure 1. illustrates the complex processes of the nitrogen cycle on a watershed, and the role of herbivores in the nitrogen cycle.

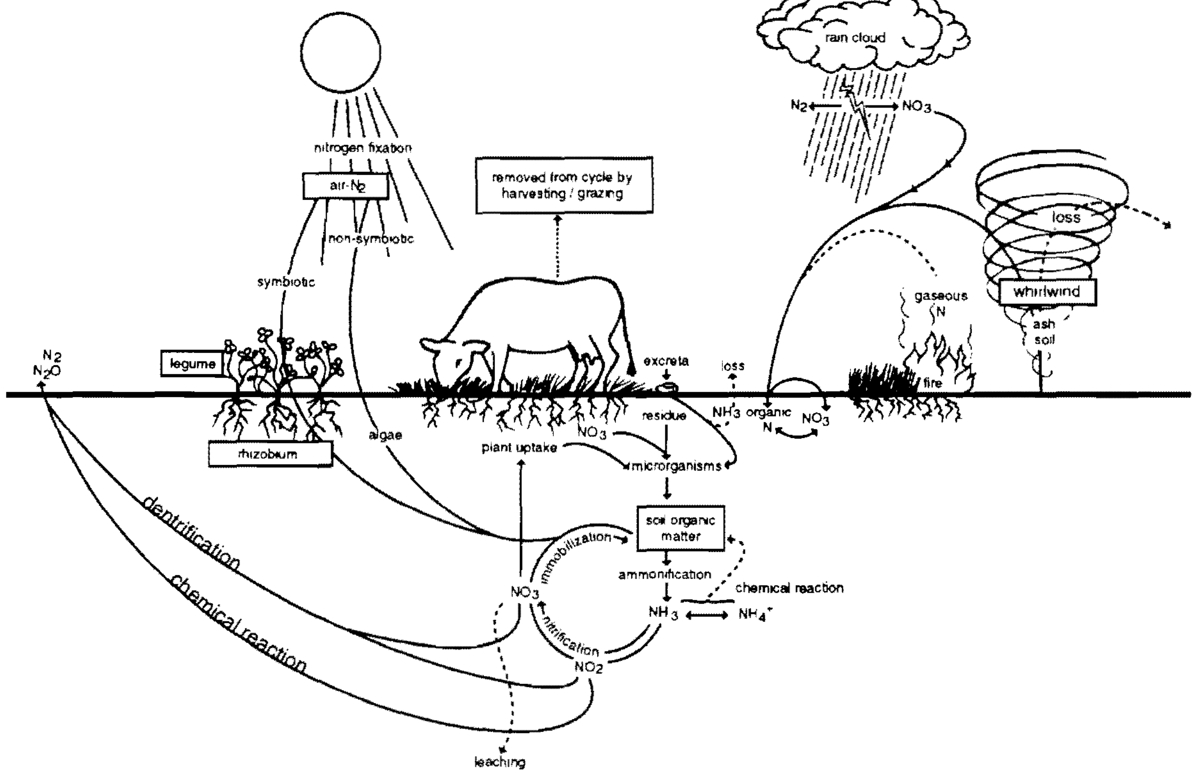

Figure 1. Nitrogen Cycle

Evaluation of nutrient discharges must also consider the natural input by rain. Olness et al. (1975) found that the rangeland watershed received more total inorganic nitrogen in rainfall than was lost in with surface runoff. Ritter (1986) found that both nitrogen and phosphorus contributed by rainfall was greater than the rates occurring in stream flow. Menzel et al. (1978) during a 4-year study found rainfall added four times the nitrogen compared to nitrogen discharged in runoff from rotational grazed pastures and about equaled the amount discharged from continuously grazed pastures.

Evaluation of rangeland cattle excrement impacts on water quality require consideration of natural variability in the hydrologic cycle, the nutrient cycles, and the pathogen cycle as well as how grazing modifies each of these processes. These factors make it difficult to quantify the amount of nutrient and pathogen loading that is attributable to rangeland beef cattle on a watershed. The purpose of this paper is to review the literature to evaluate our current knowledge of the potential for rangeland beef cattle excrement to impact water quality.

Components of Range Cattle Excrement

The feces consist of slowly digestible plant material, enzymes, mucous cells of the digestive tract, pathogens, surplus salts, wastes from cellular metabolism, and water (Azevedo and Stout 1974). Urine contains waste products of metabolism. The amount of excreted feces will depend on forage intake (driven by body size and physiological function) and digestibility.

The actual amount of urine produced daily varies according to production (growth, lactation, or conception), air temperature, and water consumption. (NRC 1984). A review of range forage intakes by Cordova et al. (1978) showed that they were highly variable with a ranging from 40 to 90 g Dry Matter /Weight(kg)$^{.75}$. Several studies in the western United States estimates intake ranging from 1 to 2.8% of body weight. Many water quality studies (Lahonton 1985, DWR 1979) are based on confined beef cattle excretion data, which should be used as only crude first estimates of rangeland cattle excretion. The following are values used by agricultural engineers based on a wide range of confined beef cattle diets and conditions. Beef cattle produce 30 to 49 pounds of urine per day. Beef cattle produce between 29 and 72 lb. of feces per day. For every ton of live animal mass, beef cattle excrete 0.748 lbs. of Kjeldahl nitrogen, 0.189 lbs. of ammonia nitrogen, 0.20 lbs. of phosphorus per day (ASAE 1992). The ASAE data did not give a dry matter output, but Azevedo and Stout (1974) give the range of percent of fresh weight to dry matter of 15 - 27%. The range in confined beef cattle output was 29 to 60 lbs. of raw and 4.6 to 10.2 lbs. on a dry matter basis.

Actual rangeland fecal output studies using collection bags illustrate the amount of variation found under rangeland conditions (Table 1). Authors report their findings on a daily fecal output on a dry matter basis. Connor et al. (1963) was the only one to publish the dry matter digested percents which were 40.4 for Southern Nevada and 53.3 for Northern Nevada.

Table 1. - Fecal Output Studies

Animal Weight (Lbs.)	Daily Fecal Output (Lbs.)	Location	Forage	Month	Author
460	3.78	So. Nevada	desert Shrub	July to October	Connor et al. 1963
460	2.68	No. Nevada	sagebrush/grass	June to Sept.	Connor et al. 1963
605	5.1 - 7	Eastern Oregon	crested wheatgrass	April-May	Handle et al. 1972
605	5.1 - 7	Eastern Oregon	crested wheatgrass	June	Handle et al. 1972
726	5.9	Nebraska	tall wheatgrass	September	Adams et al. 1991
880	5.5	Nebraska	meadow	July	Hollingsworth et al. 1995
880	8.4	Nebraska	meadow	September	Hollingsworth et al. 1995
880	7.9	Nebraska	meadow	October	Hollingsworth et al. 1995

Nutrients

Nitrogen and phosphorus are the nutrients which cause most water quality concerns.

Nitrogen

Cattle intake nitrogen mainly in the form of plant protein. Nitrogen is lost through eructation, belching, and excretion. The amount of nitrogen consumed by beef cattle that is utilized depends on the demands for growth, maintenance, reproduction, and lactation. This leads to a wide variation in reported utilization. Young calves utilize about 42% of consumed nitrogen (Salter and Schollenbergen 1939). Woodmansee et al. (1981) stated that cattle commonly retain 15 to 20% nitrogen of ingested forage. While Afzal and Adams (1992) indicated that typically 75% of the ingested N is returned in dung and urine. Azevedo and Stout (1974) reported nitrogen was excreted in urine (47.6%) and feces (52.4%) by weight. However, many researchers suggest urea accounts for about 75 percent of the excreted nitrogen (Afzal and Adams 1992). Excreted nitrogen, mainly in the form of urea, is rapidly hydrolyzed by ubiquitous urea-decomposing enzymes yielding ammonia. More than 80% of the nitrogen in urine may be lost by volatilization.

Under simulated feedlot conditions, Stewart (1970) found that 85 to 90% of nitrogen in urine was lost as ammonia. Under ambient conditions losses are probably about 50%, which is the often used value (Woodmansee et al. 1981). Nitrogen in feces that is not volatilized is slowly released from complex organic compounds present in manure as a result of microbial activity. The microorganisms which decompose manure demand a carbon-to-nitrogen ratio of less than 15 or 20 before ammonia can be split off and released from nitrogenous organic compounds in sufficient quantities for good plant growth. As decomposition proceeds, the various organic constituents of the substrate are attacked at different rates. Stewart (1970) reported that 37.3% of the nitrogen present in fresh feces was volatilized within one week. Wilkinson and Lowery (1973) reported soil N is affected in an area .97 square feet around each defecation 3.0 square feet around each urination Grass growth was affected within an area of 10.76 square feet around each urination spot. Woodmansee et al. (1981) estimated that in low productivity systems, the amount of nitrogen added in one urine patch may be 10 times greater that the uptake capacity of the plants, and in highly productive systems, the amount of nitrogen added maybe three times the uptake capacity. Nitrogen not taken up by the plants may be immobilized by soil microorganisms or eventually transferred to soil organic matter. Ammonium may be absorbed onto soil colloids or fixed and lost from the rapid cycling pools, but would slowly become available. Afzal and Adams (1992) found that total mineral nitrogen under feces was always shallow (0-.78 inches). The depth of total mineral nitrogen from urine changed with time. The change in form of total mineral nitrogen to nitrate and depth was observed at 56 days after simulated urine application with an increase of nitrate from 61% in the 0 to .78 inches depth to 98% in the 1.57 to2.36 inches depth. Dormaar et al. (1990) found that grazing did not change the total nitrogen in the Ah horizon, but the forms were different with higher ammonia and nitrate present. Nitrate is susceptible to loss by leaching if precipitation is heavy, but in most grasslands such losses are probably small (Woodmansee et al. 1981). Most elements in feces of large animals are bound in relatively resistant organic fractions (Float and Torrance 1970). The bulk of bound elements remains for many years at the surface in feces (Angel and Wicklow 1975). Fecal nitrogen is very efficient for plant growth because of the slow release (Dormaar et al. 1990). Cattle grazing removes herbage from large areas in a pasture, but deposits feces in a small area. Buckhouse and Gifford (1976) found .02% of a semi arid range covered with bovine feces under a stocking rate of 4.9 acres/AUM. Uneven distribution of excreta may affect the nitrogen cycling in the soil-plant-animal system.

Phosphorus

Phosphorus is an essential nutrient for growth, maintenance, lactation, and reproduction of cattle.

Phosphorus and calcium are important in the formation of bones. Dietary phosphorus retained by the animal varies from 78% for growing calves to 58% for lactating cows (NRC 1984). Every 2.2 pounds of calf gain contains nine grams of phosphorus, while every 2.2 pounds of cow gain contains six grams. Most excreted phosphorus (97.3%) is in the feces. Of the nutrients present in manure, phosphorus is the second most resistant to leaching. In general, phosphorus from applied manure is not leached from soils (Azevedo and Stout 1974). Phosphorus is rapidly hydrolyzed and chemically precipitated or absorbed by other soil minerals. Most soils are able to rapidly tie up large amounts of this element in forms not readily available to plants. Phosphorus is absorbed by plants as H_2 PO_4, HPO_4 or PO_4. Most soil phosphorus is tied up chemically in compounds of limited solubility. In neutral to alkaline soils, calcium phosphate is formed, while in acid soil, iron and aluminum phosphates are produced.

Pathogens

Bacteria

The primary pathogenic bacteria found in beef cattle excrement includes *Escherichia coli, Leptospira interrogans, Salmonella spp., Campylobacter jejuni and Yersinia enterocolitica* (Gary et al. 1983, Altekruse et al. 1994, Whipp et al. 1994).

Protozoal Parasites

The primary water-borne protozoa potentially transmitted by cattle excrement includes *Cryptosporidia parvum* and *Giardia duodenalis* (also known as *Giardia lamblia*) (Fayer and Ungar 1986, Craun 1990, Atwill 1996). *C. parvum* is a tiny protozoal parasite that can cause gastrointestinal illness in a wide variety of mammals, including humans, cattle, sheep, goats, pigs, and horses. It also occurs in various wildlife species such as deer raccoons, opossums, rabbits, rats, mice, and squirrels (Fayer and Ungar 1986). In cattle, shedding of the parasite is usually limited to calves, but there are a few reports of subclinical shedding in adult cattle (Lorenzo et al. 1993). Dairy calves are commonly infected with *C. parvum* and *G. duodenals* (Ongerth and Stibbs 1989, Xiao 1994), but little is known of their distribution in beef cattle herds, particularly in those herds located on open range.

Water Quality Impacts Related to Rangeland Beef Cattle Excrement

Nutrients

Hathaway and Todd (1993), studied the contribution of different cultural activities in the Wood River sub basin in eastern Oregon. They found that continuously grazed irrigated meadows did not influence the nitrogen loading of streams. The daily load of phosphorus was lower on the downstream grazed area than the upstream pristine land use area. Gary et al. (1983) studied a moderately grazed pastures bisected by a small perennial stream in central Colorado. Only minor effects on water quality were detected during a two-year study. Cow excretion was monitored for an eleven hour period both years and 6.7 to 10.5% of the defications and 6.3 to 9% of the urinations were deposited directly in the stream. Nitrate nitrogen did not increase, and ammonia nitrogen increased significantly only once during this study. Tanner and Terry (1991) found no significate differences in N, P, chlorophyll, dissolved oxygen, and pH of surface water collected from light to moderately grazed and ungrazed wetlands in south Florida. Dahlgren and Singer (1991) found that grazing of northern California oak woodlands had no effect on major nutrients. Coltharp and Darling (1975) found no difference in water chemical levels between grazed and ungrazed areas along three mountain streams. Robbins (1979) stated that all the available data indicate that pollutant yields from rangeland are not directly related to the number of animals or amount of waste involved, but are related to hydrological and management factors involving erosion/sedimentation.

Pathogens

Detailed studies that attempt to link rangeland cattle grazing with the presence of water-borne pathogenic bacteria have for the most part not been done (Atwill 1996). Instead, indicator bacteria have been used. These studies need to be interpreted with some caution since indicator bacteria have been shown to be poorly correlated with some pathogenic bacteria such as *Campylobacter jejuni* (Carter et al. 1987, Bohn and Buckhouse 1985). An increase in indicator bacteria in waterways, due to cattle grazing has been documented in many studies (Gary et al. 1983, Robbins 1979, Dixon et al. 1979, Stephenson and Street 1978). However grazing has also been found to have little or no effect on fecal indicator counts (Frear 1983, Buckhouse and Gifford 1976). Fecal indicators may not always signify the presence of pathogens in the water column (Bohn and Buckhouse 1985). When contamination does occur, it may be temporary and short-lived (Gary et al. 1983, Robbins 1979), or may persist for several months. (Stephenson and Street 1978). Furthermore, concentrations tend to decrease downstream (Robbins 1979).

A special concern for bacterial pollutants is their ability to survive in the environment, only to become a factor in pollution at a later time. Bacteria such as *Salmonella newport* and E. coli have been shown to survive several months in freshwater sediments (Burton et al. 1987). Fecal coliforms may survive up to two months in soil, but in the protective medium of feces, can persist up to a year (Bohn and Buckhouse 1985). Bottom sediments have been found to harbor concentrations of indicator organisms up to 760 times greater than the overlying water (Stephenson and Rychert 1982).

Studies that carefully evaluate the association between rangeland cattle and the presence of these water-borne protozoa have not been done. The majority of the existing literature deals with dairy cattle, or was conducted in laboratory settings. These studies do not explicitly state how the cattle were managed nor define the cattle's proximity to contaminated water bodies. Madore et al. (1987) measured 5,800 *Cryptosporidium* oocysts/L in irrigation canal water running through agricultural acreage with cattle pastures compared to 127 oocysts/L in river water subject to human recreation and 0.8 oocysts/L for stream water exposed to ranch land runoff. Unfortunately, the authors do not specify if the cattle were beef or dairy cattle or if the species of *Cryptosporidia* was the of human health concern, *parvum*. Presently, there are no data that indicates rangeland cattle are a significant source of *C. parvum* (Atwill 1996).

Spatial Distribution of Cattle Excrement

Nonpoint pollution caused by cattle excrement may be aggravated or ameliorated by the proximity of deposition to water bodies. Deposition outside of riparian areas may pose no pathogen or nutrient problems (Blackburn et al. 1982). Larsen et al. (1993) utilized a rainfall simulator in a laboratory environment to assess the effectiveness of vegetative filter strips to attenuate fecal coliforms, a questionable indicator of pathogens. Results during a 30 minute simulation indicate that distance of the fecal material up slope from the collection point significantly influences loading. In a situation where a stream was the only source of water and cattle spent 65% of the day within 328 feet of the stream channel 6.7 to 10.5% of defecations and 6.3 to 9.0% of urinations were deposited directly into the stream (Gary et al. 1983). Larsen et al. (1988) found that free ranging cattle in Oregon deposited an average of 3.4% of their feces in the stream in August and 1.7% in November. Powell (1984) found that direct overland flow movement of dung into stream channels was minimal because of standing vegetation and ground litter.

On a grazing allotment in the Blue Mountains of Oregon, riparian areas covered only 2% of the acreage, yet accounted for 81% of the herbaceous vegetation consumed by cattle (Kauffman and Krueger 1984). The preference of cattle for riparian areas has been attributed to the quality and quantity of forage, slope, microclimate, and availability of water (Bryant 1982, Marlow and Pogacinik 1986, Kauffman et al. 1983). The season of grazing can also greatly affect the use of upland pastures. Cattle do find other watershed areas preferable to riparian areas at various times of the year. Bryant (1982) found that from mid-July to mid-September, cattle in northeastern Oregon tended to graze under the forest canopy both for the shade provided and the quality of forage during this period. He also found that from mid July to mid August, cows tended to stay closer to water than yearlings. From mid August to mid September, both tended to remain near the watering sites equally. From mid September to mid October, water was ineffective for distributing both cows and yearlings. It is generally found that cows not nursing calves and yearlings tend to distribute more on the rangeland. In tallgrass prairie, the preference for bed grounds and shaded areas played a larger role in dung distribution than did quality of forage (Powell 1984). Uplands are favored over forested and riparian zones late in the season and following thunderstorms (Fear 1983, Bryant 1982). Dung fouling could act as a natural concentration constraint for high stocking rates, as cattle will avoid grazing an area 6 times the size of the feces (Sweeten and Reddell 1978).

Strategy for influencing livestock distribution

Livestock's distribution within a watershed can be manipulated using sound range management practices such as salting, water location, fencing, and selecting against cattle that graze riparian areas. Salt, mineral or protein supplements placed next to the streams can result in direct pollution of the water as well as increase cattle dung, urine and trampling next to the stream. Salt should be placed in areas away from stream courses to help distribute cattle. It is best to familiarize animals with the location of salt by driving them there, especially in an area not frequently grazed. Alternative water sources, such as windmill or solar powered wells, reservoirs, and guzzlers, can be developed in upland areas to draw cattle away from streams. Miner et al. (1992) found that a water trough 328 feet from a stream during the winter reduced the amount of time cattle spent in a stream by 90%. In the spring time, Clawson (1993) found that water trough placement reduced the range of stream use from (3.9 - 8.3) to (.9 - 4.7) minutes/cow/day. He also found that a water gap completely eliminated fecal deposition into the stream. Livestock distribution away from riparian areas may be improved through training and selection (Gillen et al. 1984, Howery 1993, Roath and Krueger 1982, Walker 1995).

Subdividing large pastures to exert more control over the frequency and timing of grazing can be used to improve grazing distribution. Rotational grazing management can be used. Continuously grazed rangelands contributed at least four times more nitrogen and phosphorous to the watershed compared to rotationally grazed rangelands. (Khaleel et al. 1979).

Conclusions

Nutrients

Water quality data should be examined carefully before assigning a cause and effect relationship between cattle grazing and non point pollution. Natural background levels of nutrient and pathogen loading can be quite high during storm events. Non point pollution from pastured and rangeland livestock depends on the stocking rate, length of grazing period, the season of use, manure deposition sites and concentration. Normally, pastures and rangelands have not presented water quality problems caused by cattle excrement, except under special circumstances. Several studies have concluded that cattle excrement contributes negligible nutrient pollution to waterways (Hathaway and Todd 1993, Frear 1983, Robbins 1979, Dixon 1979, Johnson et al. 1978, Tanner 1991, Coaltharp and Darling 1975, Milne 1976). Unfortunately, none of the studies defined the treatments well enough to describe the intensity and timing of grazing. The main water quality concerns are from cattle feces and urine deposited directly into the water. Potential problems occur in cases where animals congregate for feeding, watering, resting, in proximity to waterways, (Khaleel et al. 1979).

There is little scientific evidence that excrement from beef cattle on rangelands significantly impacts water quality. When significant nutrient contaminations do occur, especially phosphorus, they are more likely explained by erosion and sediment processes in the watershed (Khaleel et al. 1979, Robbins 1979). Cattle can effect the erosion and sediment process through vegetation removal.

Pathogens

The scientific evidence implicating beef cattle as a significant source of *C. parvum* or *G. duodenalis* for surface water is incomplete and contradictory. Given the lack of scientific investigation, it would be premature to claim that rangeland cattle production is the leading source of *C. parvum* or *G. duodenalis* for surface water contamination (Atwill 1996). Rangeland beef cattle excrement may increase pathogen contamination in water ways beyond background levels, but studies have shown that background levels are not zero. Wildlife species, including muskrats, coyotes, mule deer, waterfowl, elk, etc. shed pathogenic bacteria such as *Campylobacter jejuni* (Altekruse et al. 1994). *Giardia* has been repeatedly isolated from wildlife (Thompson and Reynoldson 1993). Furthermore, high counts of indicator bacteria are often found upstream from grazed areas and are attributed to wildlife (Gary et al. 1983). Concentrations of *Cryptosporidium* oocysts from pristine surface waters have been 0.005-18 oocysts/L, indicating that this organism occurs naturally in pristine watersheds (Sterling and Arrowood 1993).

Management Implication

Rangeland water quality can be managed by implementing spatial distribution of cattle through salting, upland water developments, fences for pasture rotation, and even by training or selection of the cattle grazed. These methods address the deposition of excrement near waterways, but also other, hydrologic, ecologic, and economic issues.

Future Direction

Future research needs to be focused directly on monitoring grazing impacts on nutrient and pathogen dynamics at the watershed scale. Clearly defining the site conditions, grazing management, and excrement depositional patterns on the watershed are critical for interpreting and applying this information.

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RANGE SCIENCE REPORT

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Rainfall Depth, Duration, and Return Frequency Information for Typical California Annual Rangelands

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Introduction

Hydrologists, managers, planners, and engineers are often interested in estimating the amount and return frequency of probable future rainfall events. Unfortunately, the occurrence of future rainfall events such as the 100-year, 24 hour storm is inherently random and thus unpredictable. We know it will happen, we do not know when (see UC RWP Fact Sheet No. 35, *Exactly What is a 100-Year Event?*).

With varying degrees of confidence, we can employ frequency analysis to predict the depth of rainfall expected for a specific storm event from historic rainfall data. The amount of confidence we have in our estimate depends in large part upon the duration of the historic record. We would be fairly confident in estimating the 5-year, 2 hour storm from 50 years of record. However, we would be less confident predicting the 25 or 50-year, 2 hour storm from that same record.

Basing the design of hydrologic structures, such as road culverts, upon probabilistic estimates of storm size allows an engineer or planner to assign some level of risk (probability) of the failure of that structure.

The amount (concentration or load) of a nonpoint source pollutant (sediment, nutrients, pathogens, etc.) generated and transported during rainfall events can be examined under storm events of various magnitudes. This allows us to assign some probability (risk) that a certain load or concentration will be exceeded under certain conditions. For example, we are using rainfall depth estimates for the 2-year and 50-year return frequency, 4 hour duration storm at Brown's Valley, CA to design simulated rainfall events to examine the hydrologic transport of *Cryptosporidium parvum* oocycts (eggs) from cattle fecal deposits on annual rangeland.

We will soon be utilizing this information in the design of simulated storm events in a field study of the relationship between ground cover by herbaceous vegetation and erosion.

Objective

The objective of this Range Science Report was to synthesize existing rainfall data to characterize precipitation patterns at four representative California annual range / oak woodland locations. Making this information readily available for planning of future research.

Depth-Duration-Frequency Rainfall Information

Precipitation patterns at rainfall dominated locations, such as California's annual rangelands, are traditionally defined in terms of rainfall depth-duration-frequency (DDF). In developing DDF information, historic rainfall records are utilized to estimate the Depth (in) of rainfall one can expect from a storm of a given Duration (hours) occurring on a given Frequency (years) for the location.

Hershfield (1961) analyzed historical records and developed DDF information for much of the continental United States. He developed DDF information for storm durations of 0.5, 1, 2, 3, 6, and 12 hours with return frequencies of 1, 2, 5, 25, 50, 75, and 100 years. Hershfield presents this information in the form of a series of atlases of the continental United States with isohyetal lines connecting locations of equal rainfall depth for a specific combination of duration and frequency.

Although a bit dated, the document still serves as the most used reference of its kind for the western United States. Hershfield's set of atlases represents a significant effort. One which is unlikely to be updated, or expanded on a National scale again. Where available, the longest, most consistent local rainfall records should be employed when specific DDF information is required.

DDF Information for CA Annual Rangelands

For this report we compiled DDF rainfall information from Hershfield (1961) for four representative sites within California's annual rangelands. The sites were chosen to represent southern Sierra foothill, northern Sierra Nevada foothill, north coast, and central coast annual rangelands. In that order, the sites selected were: 1. USFS San Joaquin Experimental Range (SJER) in Madera County; 2. UC Sierra Foothill Research and Extension Center (SFREC); 3. UC Hopland Research and Extension Center (HREC) in Mendocino County; and 4. Paso Robles, CA (Paso R.) in San Luis Obispo County.

For each location, the expected depth (in) of the 1, 2, 3, 6, 12, and 24 hour duration 1, 2, 5, 10, 25, 50, and 100 year return frequency storm was compiled. This information is listed in Tables 1 through 4. It is also presented graphically in Figure 1. The expected rainfall depth (y-axis) for a given duration (x-axis) storm for a given return frequency (plotted lines) can be read for each location.

Figure 2 is a plot of rainfall depth for the 100-year return frequency 1 hour, 6 hour and 24 hour storms across locations. Note that an average of the four locations has been plotted with the data. The plots are nearly identical for all 4 locations for the 100-year, 1 hour storm. SJER separates out from the other three sites for the 100-year 6 and 24 hour storms. It is also interesting how similar precipitation patterns are for SFREC, HREC, and Paso Robles across all three storms. It is important to point out that this similarity is in individual storm characteristics, and not annual rainfall amount (the number of storms).

Literature Cited

Hershfield, D.M. 1961. Rainfall frequency altas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. Technical Paper No. 40. U.S. Weather Bureau.

Table 1. Rainfall (in) Depth-Duration-Freauency Data for SJER.

	Duration (Hr)					
Frequency (Yr)	1	2	3	6	12	24
1	0.50	0.60	0.80	1.00	1.50	1.70
2	0.60	0.75	1.00	1.30	1.75	2.00
5	0.90	1.00	1.25	1.75	2.20	2.50
10	1.00	1.25	1.50	2.20	3.00	3.50
25	1.20	1.50	1.75	2.75	3.50	4.20
50	1.40	1.75	2.00	3.00	4.00	5.00
100	1.50	2.00	2.25	3.25	5.00	6.20

Table 2. Rainfall (in) Depth-Duration-Frecuency Data for SFREC.

	Duration (Hr)					
Frequency (Yr)	1	2	3	6	12	24
1	0.60	1.00	1.25	2.00	3.00	3.50
2	0.70	1.10	1.60	2.50	3.50	4.00
5	0.80	1.30	1.80	3.00	4.00	4.75
10	1.00	1.60	2.10	3.50	5.00	6.00
25	1.15	2.00	2.50	4.25	5.50	7.00
50	1.25	2.20	2.80	5.00	6.50	8.00
100	1.50	2.35	3.00	5.50	8.00	10.00

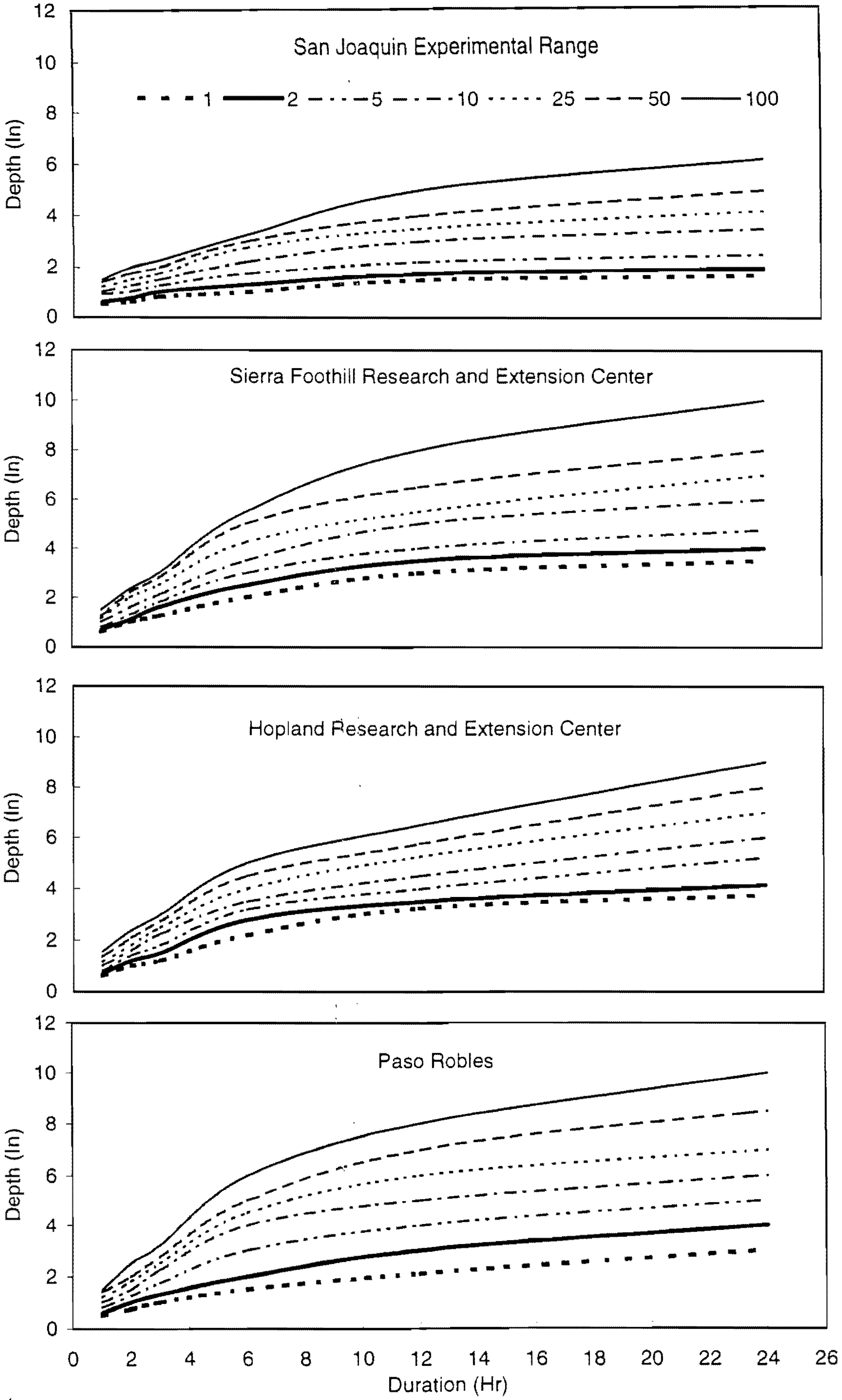
Table 3. Rainfall (in) Depth-Duration-Frequency Data for HREC.

	Duration (Hr)					
Frequency (Yr)	1	2	3	6	12	24
1	0.60	1.00	1.20	2.20	3.25	3.75
2	0.70	1.20	1.50	2.80	3.50	4.15
5	0.80	1.40	1.80	3.20	4.00	5.20
10	1.00	1.60	2.25	3.50	4.50	6.00
25	1.15	1.80	2.50	4.00	5.25	7.00
50	1.35	2.10	2.75	4.50	5.75	8.00
100	1.55	2.40	3.00	5.00	6.50	9.00

Table 4. Rainfall (in) Depth-Duration-Frequency Data for Paso Robles.

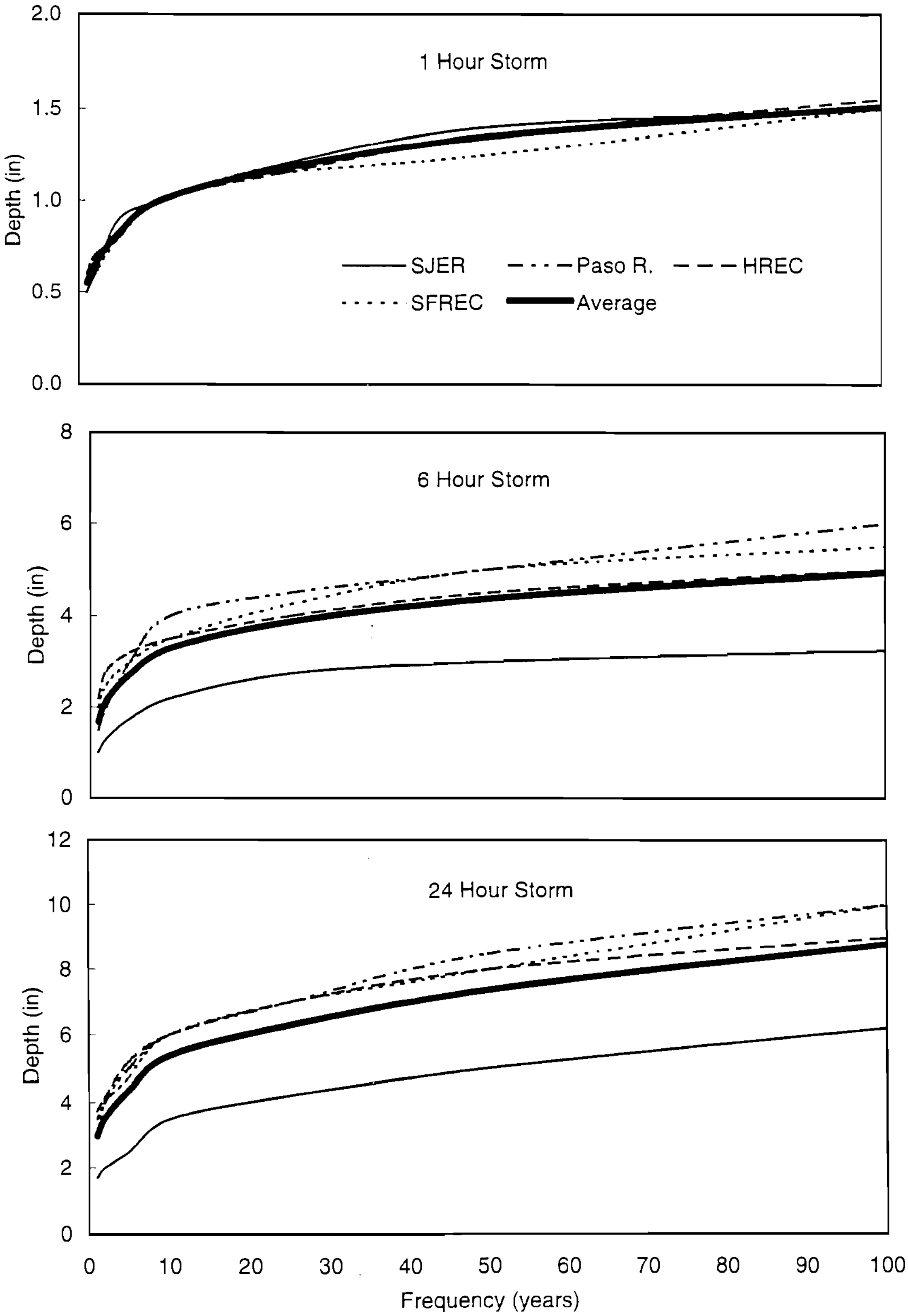
	Duration (Hr)					
Frequency (Yr)	1	2	3	6	12	24
1	0.50	0.75	1.00	1.50	2.10	3.00
2	0.60	1.00	1.30	2.00	3.00	4.00
5	0.80	1.25	1.75	3.00	4.00	5.00
10	1.00	1.50	2.25	4.00	5.00	6.00
25	1.20	1.80	2.50	4.50	6.00	7.00
50	1.40	2.00	2.75	5.00	7.00	8.50
100	1.50	2.50	3.20	6.00	8.00	10.00

Figure 1



San Joaquin Experimental Range
1
2
5
10
25
50
100
Sierra Foothill Research and Extension Center
Hopland Research and Extension Center
Paso Robles
Depth (In)
0
2
4
6
8
10
12
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Duration (Hr)

Figure 2



1 Hour Storm
Depth (in)
2.0
1.5
1.0
0.5
0.0
SJER
Paso R.
HREC
SFREC
Average
6 Hour Storm
Depth (in)
8
6
4
2
0
24 Hour Storm
Depth (in)
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
Frequency (years)