rose pussytoes, trailing fleabane, and fringed sagebrush occurred on lightly, moderately, and heavily grazed range.

The ungrazed ranges were characterized by comparatively small numbers of large plants per given unit of area, although Arizona fescue occurred in markedly greater numbers on the ungrazed areas than under any other treatment. The grass tufts were large and uniformly distributed over the plant crowns. Heavily grazed areas were characterized by a larger number of smaller plants of some species with smaller grass tufts usually confined to the outside edge of the crown. Arizona fescue plants were both fewer in number and smaller in size on the heavily grazed area than under the other grazing intensities.

Grass seedlings were most abundant on ungrazed areas. There was no apparent difference in the density of grass seedlings on ranges grazed at heavy, moderate, or light intensities.

Weed seedlings were closely correlated with intensity of grazing. Rose pussytoes, trailing fleabane, and fringed sagebrush seedlings were most abundant on heavily grazed areas. Nickleaf milkvetch seedlings were most abundant on ungrazed areas.

The effect of grazing on production of seedstalks was obscured by adverse weather effects. Little bluestem and mountain muhly were the only species to show a correlation between seedstalk production and grazing intensity.

Height of leaf growth was the most consistent plant response to the different grazing intensities. Leaf growth was shortest on areas that had received heavy grazing and longer under the lighter grazing intensities. Variations in weather also have an effect on height of leaf growth, but differences between the different grazing intensities were consistent.

Root development in relation to top growth was impaired by heavy grazing use. No impairment of root growth was observed under moderate and light grazing.

Herbage yield of perennial grasses and sedges was greatest on ungrazed range and progressively less on the lightly, moderately, and heavily grazed ranges. Blue grama produced more on the heavily grazed range and least on the lightly and ungrazed ranges, whereas mountain muhly and Arizona fescue were least productive on the heavily grazed areas. Low valued weeds and fringed sagebrush tended to be most productive on heavily grazed ranges.

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CHANGES IN A CALIFORNIA ANNUAL PLANT COMMUNITY INDUCED BY MANIPULATION OF NATURAL MULCH[1]

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The dead plant materials above the soil surface in natural grasslands are usually referred to as litter, mulch, or plant residue. This material varies in position from lying directly on the soil to standing upright in a tangled mass. It may also be in all stages of decomposition and in many degrees of compactness. The kinds of plants which contribute to the mulch layer are many and therefore the nature of the material itself is varied.

For purposes of study and accurate description, the total mulch has been divided into layers. The upper portion of unconsolidated and undecomposed material is litter to the forester and the A_{00} layer in soil science. It has also been called fresh mulch and forage residue. The latter term seems the most descriptive for grasslands since much of that material may be eaten by livestock, however poor it is for feed. For example, the diet of animals grazing on the California annual type during the winter contains a considerable proportion of this material along with young and very succulent green herbage.

The partially decomposed material on the soil surface is known as raw humus, the A_0 layer or, preferably for grasslands, humic mulch. Little is ever easten by livestock. It becomes humus when decomposition proceeds to a point so that the origin of the material is no longer recognizable and

[1] This paper is based on Project No. 1501 in the California Agricultural Experiment Station.

it becomes mixed with mineral soil. Humic mulch is often missing if the total mulch layer is thin.

Mulch is used in this paper to include both layers and is a general term to be used when division into layers is unnecessary or impractical. The term "litter" should be restricted to its present usage in forestry.

These terms and definitions are in agreement with those used by Hedrick (1948) and only slightly different from suggestions made by Dyksterhuis and Schmutz (1947).

Sincere appreciation is expressed for the help in reading field plots and in making certain of the calculations that was given by Messrs. Harold Baker, James Mallory, Robert Merriam, and Lynn Rader.

Literature Review

The beneficial effects of mulches in farm crop production and in forest management have long been recognized. The manipulation and management of plant materials to protect the soil forms an important part of most soil conservation programs. The distribution, thickness, and occasionally the amount of mulch is often given importance in range management literature dealing with the appraisal and management of native grasslands. However, the foundation of quantitative data on which these statements have been made is not great and for grasslands it is scarce.

Dyksterhuis and Schmutz (1947) gave an excellent review of the literature which deals with mulches. Repetition of that review is hardly necessary but the reiteration of major findings seems pertinent. There is little doubt that a mulch layer improves soil surface conditions for plant growth and at the same time gives the soil protection against erosion. Less evaporation, less extremes in soil temperature, more organic matter in the top soil, more activity by organisms, and reduced impact of raindrops and running water are the main contributing factors. Infiltration is increased but at the same time mulch causes some water loss through interception. These may be summarized by saying that mulch improves soil structure and fertility and increases infiltration rate.

The effects on soil and water no doubt in turn influence the plants growing thereon. Increasing amounts of mulch have been shown to result in improved germination and emergence of grass seedlings (Glendening 1942). Forage production may be improved with increasing amounts of mulch (Larson and Whitman 1942, Schwan, Hodges, and Weaver 1949) but several authors have shown that accumulation of mulch could become excessive and thereby reduce forage production (Dyksterhuis and Schmutz 1947, Weaver and Rowland 1952). Any increase in mulch below optimum amounts has been said to promote plant succession but excessive amounts unquestionably smother some understory plants and reduce seed stalk formation of the dominant grasses (Weaver and Rowland 1952). A decrease in the proportion of grass and increased density in the California annual type were reported by Talbot, Biswell, and Hormay (1939) for two years following removal of mulch by hand. Hervey (1949) found similar results the first growing season after a fire.

Mulch accumulates as the above ground parts of plants die. The speed of decomposition depends upon microbial activity which require favorable combinations of temperature and moisture. These are seasonal phenomena in grasslands and result in a cycle of high and low amounts of mulch during a year (Dyksterhuis and Schmutz 1947). In addition the degree of forage removal by livestock, kinds of plants and the climate will also influence the deposition and decomposition of mulch. There is normally some carry-over of mulch from one year to the next. Hopkins (1954) in Kansas found that half the weight of materials placed on the ground was lost the first year and all had decomposed in three years.

Amount of mulch has been used as an important factor in the evaluation of range condition (Humphrey 1949). Voigt and Weaver (1951) give data from native pastures in Nebraska which show that the amount decreases with lowering condition and that changes in the composition of the mulch tend toward a high proportion of coarse materials in poor condition pastures.

These statements and studies suggest that maintenance of mulch is important in grassland management but many questions remain unanswered. What is the optimum amount which will promote maximum yearly and long-term production of forage? Is a complete cover of mulch needed at all times, is cover at certain seasons sufficient, or does only a certain proportion of the soil need to have a mulch? What are the effects of mulch on botanical composition? The following is a résumé of my experimentation to date on these questions.

Location

The experiment was conducted on the Hopland Field Station which is operated by the University of California in Mendocino County. The location is in the central part of the North Coast ranges and receives an average annual rainfall of approximately 35 inches. The experimental plots were located on a relatively level area of Sutherlin soil that supports a typical stand of plants known widely as the California annual type. Perennial broadleaved herbaceous plants are scattered and occasionally individuals of purple needlegrass (*Stipa pulchra*) and other perennial grasses are found.

The study area was located near an area where winter feeding of sheep had been done for several years previous to 1952 when the work began. The range condition was poor, being principally an area of weeds and grasses with low forage value. The high potential production and low range condition were selected so that the influence of mulch manipulation on range improvement could be studied. The use pattern outside the fenced plots was changed in 1952 and by 1955 the condition of the surrounding area had improved markedly. These changes serve as useful comparisons with the experimental results.

Methods

The experiment consisted of 64 adjacent plots each 10 feet on a side and arranged in an 8 x 8 latin square. The experimental area was enclosed by a sheep fence with a buffer strip 10 feet wide between the fence and plots. The lay-out was made in mid-winter of 1951-1952 so that a full crop of plants could be grown and measured before the first mulch treatments in August of 1952.

The outside plot corners were marked permanently with iron stakes so that all 64 could be located by stretching string in both directions across the experimental area. The 8 treatments, repeated each year on the same plots, were as follows:

1. Bare—all mulch removed and weighed.
2. Clipped to 1¼ inch stubble, clippings removed, weighed, none returned.
3. Same, 25 per cent returned.
4. Same, 50 per cent returned.
5. Same, 75 per cent returned.
6. Same, 100 per cent returned.
7. Clipped to 2½ inch stubble, clippings removed, weighed, none returned.
8. No clipping treatment or mulch removed.

Treatments 1-7 were clipped with a Scythette and the 1¼ inch stubble height is an average of the clipping height attained. The stubble and all mulch on Treatment 1 was removed by hand. The Scythette was held above the ground to attain the 2½ inch stubble height in Treatment 7. It, too, is an average measurement of height attained. Air-dry weights of the mulch were taken in the field at the time of clipping in the last week of August each year. In addition to these, the amount of mulch was sampled on one square foot of each of the 64 plots. The clippings from these were weighed after drying for 24 hours in an oven set at 100° C.

The treatments were applied in the last week of August from 1952-1955, which was at least 3 months after plant maturity and near the time when the first fall rain might occur. The time was chosen so that the least possible amount of seed would be removed with the mulch since most of it had fallen to the ground by that time. One objective was to determine the cumulative effects of mulch on botanical composition with as little disturbance of the seed crop as possible.

Sampling for forage production and botanical composition was done in late April or early May at a time near plant maturity. Sixty-four samples of one sqaure foot were clipped at ground level to determine current herbage growth on an oven-dry basis. Botanical composition was determined by the point system with 160 points used in each treatment. For each pin, all hits were recorded, the height of the first hit above the ground and whether the point hit bare soil, moss, mulch, or rocks at the soil surface.

Characteristics of the Flora and Vegetation

The flora within the exclosure used in the study is composed of at least 46 species. It is presented below in tabular form so that scientific and common names can be used separately and to give a general description of the vegetation. Even though the area described is small, the description of the vegetation typifies a much larger area. The scientific names of grasses are according to Hitchcock (1950) and all others follow Jepson (1925). The "I" and "N" in the third column refer to origin of the species in terms of introduced or native to California and is given on authority of Robbins (1940). Whether the species is annual or perennial is indicated by the "A" or "P" in the last column (Jepson 1925).

Grasses		
Aira caryophyllea—Silver hairgrass	I	A
Aristida oligantha—Prairie threeawn	N	A
Avena barbata—Slender wild oat	I	A
Briza minor—Little rattlesnake grass	I	A
Bromus mollis—Soft chess	I	A
Bromus rigidus—Ripgut	I	A
Festuca dertonensis—Foxtail fescue	I	A
Gastridium ventricosum—Nitgrass	I	A
Stipa pulchra—Purple needlegrass	N	P
Legumes		
Astragalus nigrescens—Annual loco-weed	N	A
Lotus micranthus—Dwarf lotus	N	A
Lupinus bicolor—Annual lupine	N	A

Medicago hispida—Bur clover I A
Trifolium bifidum—Pinole clover N A
Trifolium ciliolatum—Tree clover N A
Trifolium depauperatum—Dwarf sack clover N A
Trifolium microcephalum—Small headed clover N A
Trifolium microdon—Valparaiso clover N A
Trifolium variegatum—White tip clover N A

OTHER BROADLEAVED HERBS

Achyrachaena mollis—Blow wives N A
Agoseris heterophylla—Variable-leaved dandelion N A
Anagallis arvensis—Scarlet pimpernel I A
Baeria chrysostoma—Goldfields N A
Brodiaea capitata—Blue dicks N P
Calochortus venustus—White mariposa lily N P
Cerastium viscosum—Mouse-ear chickweed I A
Daucus pusillus—Rattlesnake weed N A
Eremocarpus setigerus—Turkey mullein N A
Erodium botrys—Broadleaf filaree I A
Filago gallica—Filago I A
Galium californicum—California bedstraw N P
Galium parisiense—Wall bedstraw I A
Hypochoeris glabra—Smooth cat's ear I A
Lepidium nitidum—Shining peppergrass N A
Linanthus ciliatus—Whisker-brush N A
Micropus californicus—California micropus N A
Microseris acuminata—Pointed leaved microseris N A
Oenothera ovata—Sun cup N P
Orthocarpus densiflorus—Owl's clover N A
Orthocarpus erianthus—Johnny tuck N A
Orthocarpus pusillus—Dwarf's owl's clover N A
Pentachaeta exilis—Small pentachaeta N A
Plagiobothrys nothofulvus—Popcorn flower N A
Plantago erecta—Annual plantain I A
Sanicula bipinnatifida—Purple pincushion N P
Silene gallica—Common catchfly I A

The vegetation within the exclosure contained a high proportion of annual plants (Table I). On the basis of percentage composition, the annuals contributed between 97 and 99 per cent of the foliage cover during the four years. The perennials were species of *Stipa, Brodiaea, Calochortus, Galium, Oenothera,* and *Sanicula.* These constitute 13 per cent of the 46 species in the flora but only 1 to 3 per cent of the cover.

When the breakdown is on a basis of whether the species are native or introduced, a somewhat different picture is presented. The composition contribtued by introduced species was between 80 and 97 per cent. The 16 alien plants make up 35 per cent of the floral list. Of these *Aira, Briza, Bromus mollis, Erodium, Festuca,* and *Hypochoeris* contributed all but a few per cent of the alien portion. They were at the same time the most important species in the whole vegetation in the study area. During the four years, they did not fail to make up at least 67 per cent of the entire botanical composition and in 1954 they comprised 84 per cent. Four others, *Avena, Gastridium, Bromus rigidus,* and *Medicago,* were present in very small amounts, even though they were abundant nearby and are commonly listed as important components of the California annual type. The principal natives were *Stipa,* all legumes, *Baeria, Pentachaeta, Linanthus, Daucus, Orthocarpus,* and *Lepidium.*

TABLE I. Comparison of percentage botanical composition between years and types of plants

	1952	1953	1954	1955
Annual	99	98	99	97
Perennial	1	2	1	3
Introduced	89	92	97	80
Native	11	8	3	20
Grasses	43	48	59	29
Legumes	9	6	3	17
Other herbs	48	46	38	54

The present vegetation is clearly dominated by introduced annuals. The nature of the original grassland in California is little known and much controversy exists over the relative importance of native perennials and annuals and introduced annuals. Undoubtedly, the advent of alien plants, grazing by domestic animals, and change in the pattern of burning have resulted in a different vegetation than that of a century or two ago. A discussion of these points is not intended here but it does seem pertinent to record an observed change near and within the exclosure used for the experiment.

When the area was selected in late 1951, not a single plant of *Stipa pulchra,* a perennial bunchgrass, was noticed either in the exclosure or in the immediate vicinity. This was also true during the sampling at the end of the 1952 growing season. In late April of 1953, there were 193 small plants of *Stipa pulchra* within the exclosure and a scattering of them in the adjacent area. The number was 220 in 1954, and 612 in 1955 at which time there were large mature plants and many seedlings. A similar increase was apparent outside the exclosure but grazing prevented the formation of large bunches. *Stipa* plants were found in many of the mulch plots but no relationship to the treatments could be detected. The spread of this plant is continuing but how thick the stand will become and whether other perennial grasses will appear are still points of speculation.

The general appearance of the vegetation is that of grass even though the proportion of grass species has been only between 29 and 59 per cent. These plants are tall and remain standing during the dry season. The legumes are short and form an understory which is never obvious except upon close examination. The broadleaved herbs shatter and largely disappear shortly after they mature.

In some years and locations, *Lupinus bicolor* gave a brilliant blue aspect for a short period when it was in flower. *Erodium botrys* was neither tall nor did it have conspicuous flowers and even though it was abundant, the contrast in appearance was only on shade of green. In areas where grass was scarce, and in early spring when the grass was short, there were often patches of brilliantly colored flowers. The two most common of these were first the light yellow of *Orthocarpus erianthus* and later the orange-yellow of *Baeria chrysostoma*. Mixed with them were white splashes of *Calochortus venustus, Daucus pusillus, Plagiobothrys nothofulvus,* and others. In addition to the lupine, scattered spots of *Brodiaea, Trifoliums, Orthocarpus,* and *Sanicula* added bits of blue and red to the aspect.

Amounts of Mulch

The average amount of mulch on an acre basis which was attained per treatment is shown in Table II and illustrated in Figure 1. Two trends are at once apparent. There has been a gradual increase in mulch for Treatments 2-8 from 1952 to 1955. The treatments with greatest proportion of current herbage growth returned to the plots have shown the greatest percentage increase in mulch over the 4 years.

Table II. Average pounds of mulch per acre on the eight treatments after manipulations in the last week of August each year

Treatments	1952	1953	1954	1955
1...........	0	0	0	0
2...........	945	1175	1310	2410
3...........	1080	1450	1510	2690
4...........	1210	1820	1960	3115
5...........	1310	2060	2000	3375
6...........	1540	2440	2475	4065
7...........	1100	1870	2065	4145
8...........	1485	2360	3220	4990

An explanation for both trends is found in the nature of the treatments themselves. Only current growth was used in the manipulation while the mulch measurements included current growth and undecomposed residue from previous years. The carry-over was apparent, especially from 1954 to 1955, and was shown by percentage of the soil surface covered (Table III) and by field observations as well as in the data mentioned above.

General differences between years in the rate of decomposition and the influence of amount of

Fig. 1. Different amounts and position of mulch September 15, 1954. Stubble height on the plot in the foreground was 2.5 inches, on the second 1.25 inches and the third plot was unclipped.

TABLE III. Percentage of the soil surface covered by mulch and moss in the various treatment from 1952 to 1955

Treatment	Mulch					Moss				
	4-4-52	4-29-53	11-4-53	4-26-54	4-26-55	4-4-52	4-29-53	11-4-53	4-26-54	4-26-55
1....	20	0	19	39	25	56	27	0	17	37
2....	15	0	79	71	70	61	23	4	4	21
3....	21	1	82	68	86	53	20	2	4	13
4....	20	1	92	74	84	68	21	0	2	11
5....	15	4	94	73	87	66	19	0	2	10
6....	22	1	97	79	97	60	25	0	2	3
7....	21	0	80	78	85	58	30	0	2	13
8....	22	1	92	80	83	40	20	0	4	8

mulch on decomposition are shown. The full extent of these differences and trends needs to be studied further before the complete cycle of deposition and decomposition can be told.

Soil Surface Conditions

In the sampling with the point system, a record was made of whether the points hit mulch, bare soil, moss, or rocks at the soil surface. Rocks will not be mentioned further because that item included only about a quarter of one per cent of the hits.

The proportion of hits on mulch, bare soil, and moss varied greatly between years with very little difference between treatments except that the bare treatment had considerably less mulch and more bare soil and moss than the others in 1954 and 1955 (Table III).

The data for 1952 were taken before any mulch manipulations were made and they reflect the conditions at the beginning of the experiment. Roughly one-fifth of the soil was bare, one-fifth covered with mulch, and three-fifths covered with moss. At the same time of year in 1953 and after one set of treatments, there was practically no mulch on any plots, only about 23 per cent was moss and the remaining soil between the growing plants was bare. The mulch could have been lost only through decomposition. The winter of 1952-1953 was relatively moist and warm, conditions favorable to rapid decomposition. At the same time, there was practically no accumulation of mulch older than that left in August of 1952. Carry-over of mulch began in this experiment with the winter of 1953-1954.

In the following two years, the percentage of the soil covered with mulch was high except for Treatment 1. The 39 and 25 per cent found there, respectively, in the two years were higher than expected because an attempt was made to remove all of the mulch each year. However, close examination showed that a layer of fine materials still remained after treatment and also, by sampling time each year some plants had lost leaves and a few had matured and scattered. The extent and pattern of this addition to the mulch was not determined.

Between November, 1953, and April, 1954, there was an expected decrease in proportion of soil covered with mulch which ranged from 2 to 21 per cent. Just why it increased at the same time for the bare plots is not known. The average temperatures were lower in 1954-1955 than in other years and consequently the extent of the mulch covering was higher in the spring of 1955 than in the other years. The first two treatments did not follow this trend; again, the reason is unknown.

Evidently moss responded to differences in yearly environmental conditions just as the seed plants did. There was relatively little in 1954 and more in 1953 and 1955. By 1955, an inverse trend with amounts of mulch was developing.

Treatments 6 and 8 deserve special mention. Both had the maximum amount of mulch. The difference was that in Treatment 6 the plots were clipped to a stubble height of 1.25 inches and all the material was returned evenly to the plots. The soil in this treatment had a high coverage of mulch. In Treatment 8, the mulch was more upright and less of the soil was covered. This difference in position of the mulch contributed to the differences in speed of growth, botanical composition, and herbage production on these plots.

Production of Herbage

The oven-dry production of plant materials varied somewhat from year to year. In 1952, the amount was low on all treatments and not significantly different between plots. Thus, the experiment began with essentially uniform conditions of low forage production. Production was higher in 1953 on all treatments, still higher in 1954 and somewhat lower in 1955 than in 1954.

The most striking feature was the difference between treatments. Where all the mulch was removed, changes in production in 4 years were not significant and in 1955 this treatment still had a uniformly low yield. Production had not improved even though there had been no disturbance of the vegetation during the growing season.

With increasing amounts of mulch in the other treatments, the production increased. The dependence of production on mulch is shown in Figure 2 by the regression line which is expressed by the equation $Y = 1214 + 0.354X$. This means that for each pound of increase of mulch there was an increase of 0.354 pound in production between the limits of 1,200 and 2,400 pounds. These data have a highly significant correlation coefficient of 0.727. Figure 2 is based on the data obtained in 1954 and 1955 only. The first two years were omitted because the effects of mulch were still accumulating.

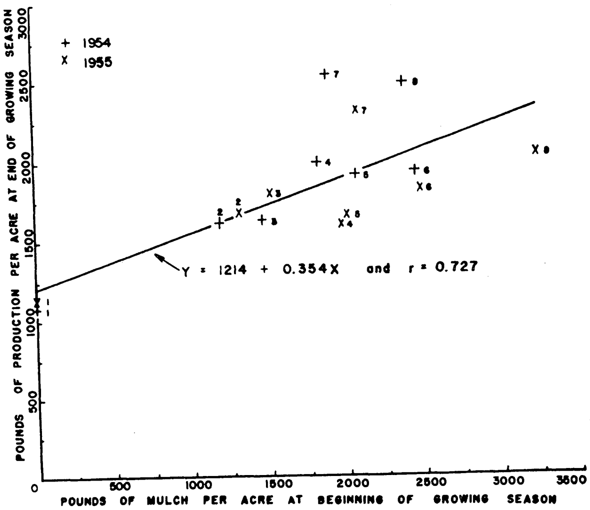

FIG. 2. Linear regression of pounds of production per acre on pounds of mulch for eight treatments in 1954 and 1955. Above 1214 pounds of production there is an average increase of 0.354 pounds of production for each additional pound of mulch. The correlation coefficient of 0.727 is significant at the 0.01 level.

When Treatments 7 and 8 are omitted, the relationship becomes much closer, as expressed by a correlation coefficient of 0.891. These perhaps should be omitted because they involved different stubble heights and therefore they include the factor of position of the mulch as well as the amount. However, the regression equation is little different when they are excluded except that the *beta* coefficient as a much narrower range of variation.

At this point, a discussion of the predictive value of the chart should be made. The experiment included the removal of all current growth each year as well as the removal of none. Neither of these conditions is practical in a grazing program aimed at maximum livestock production for the long-run. Somewhere between the two extremes should be a point of maximum sustained production. The proposal of a single point is not logical from these data alone because the relationship is linear and without a breaking point of production indicated. Other factors must be considered such as botanical composition, speed of growth, length of growing season, soil stability and, above all, the animal requirements and over-all ranch operation before a level of proper use can be indicated.

The herbage production data are from samples clipped at ground level. The amount of mulch needed to allow a certain production can be read from the graph. For example, 2,000 pounds of mulch per acre are needed to obtain about 1,800 pounds of production. At first glance, this would indicate that none of the forage could be harvested because production is less than the mulch. However, some can be harvested because a portion of the mulch is carry-over from previous years. The amount of carry-over is greater with materials standing upright than with those flat on the soil surface. Since the amount of plant materials that decomposed completely each year varied a great deal and was not satisfactorily determined, Figure 2 cannot be used to determine the amount of forage that can be harvested by livestock. Production alone should not be the sole consideration in determination of proper use because proper kinds of plants and quality of forage are also needed for profitable livestock production. In short, these data show the dependency of herbage production on amounts of mulch but they do not differentiate between current additions to the mulch and carry-over. This must be done before interpretations of proper use by livestock can be made.

Vegetational Differences Between Treatments

Differences in botanical composition between treatments were not significant at the end of the first growing season in 1952. *Bromis mollis* made up 2.3 per cent of the composition, other grasses 40.6 per cent, *Erodium botrys* 15.4 per cent, all legumes 9.4 per cent, and all other broadleaved plants 32.3 per cent (Table IV). Analysis of variance after angular transformation showed no significant differences between the treatments within any of these groups. Thus, the initial objective of essentially uniform composition between the mulch treatments was accomplished. There were some location effects as indicated by significant differences in the rows and columns. These were expected and were the principal reasons for using the latin square design. By so doing, the variance due to location could be separated from the variance due to treatment.

Several trends in composition became apparent in successive years. Some were striking by 1953 and others developed more slowly. Several species responded very definitely to the mulch treatments while others did not. Some were favored when all the mulch was removed, others when none was removed and a third group reached a

TABLE IV. Percentage botanical composition for treatments and years. Each percentage is an average of eight replications in a latin square design

	Year	Treatments								Average
		1	2	3	4	5	6	7	8	
Bromus mollis	1952	0.9	2.0	2.6	2.3	6.5	0.8	1.8	2.7	2.3
	1953	4.4	12.9	11.4	14.6	14.3	12.7	7.0	14.5	11.5
	1954	1.9	11.0	5.5	16.1	12.4	12.4	16.4	37.3	14.1
	1955	0.9	6.0	7.0	7.4	7.4	12.9	16.8	25.8	10.5
Other grasses	1952	43.6	50.2	44.1	39.2	31.5	36.5	42.3	36.4	40.6
	1953	39.9	34.3	40.9	27.2	29.6	34.8	47.1	36.6	36.3
	1954	47.4	45.9	52.8	39.9	45.3	40.3	54.6	31.3	44.7
	1955	34.0	30.0	16.0	18.1	12.5	12.0	13.9	11.0	18.4
Legumes	1952	6.8	11.1	11.0	10.8	7.6	7.1	8.1	12.7	9.4
	1953	5.4	7.9	6.0	6.3	10.6	6.3	0.6	5.2	6.1
	1954	2.8	5.9	4.2	1.6	1.5	2.1	0.9	1.5	2.6
	1955	4.5	20.8	24.2	19.4	21.3	17.7	17.9	8.2	16.8
Erodium botrys	1952	14.5	17.2	7.6	13.8	17.4	15.9	15.3	22.7	15.4
	1953	15.3	20.2	12.8	23.8	19.1	16.3	17.8	34.3	20.1
	1954	22.3	21.2	18.3	18.1	16.3	19.7	16.7	17.0	18.7
	1955	35.0	29.3	25.5	36.9	36.1	36.3	38.7	40.0	34.7
Other broad-leaved plants	1952	34.2	19.2	34.7	33.9	37.0	39.7	32.5	25.5	32.3
	1953	34.5	24.7	29.5	28.2	26.5	29.8	25.6	9.3	26.0
	1954	25.6	16.1	19.2	24.2	24.4	25.3	11.3	12.9	19.9
	1955	25.6	13.9	27.3	18.2	22.7	21.0	12.7	15.0	19.6

maximum composition with intermediate mulch treatments (Figure 3).

Grasses

Bromus mollis reached its highest proportion with the most mulch and was least with no mulch. It showed a definite gradation in the intermediate treatments although there was no significant difference in the proportion in Treatments 4 to 7. These changes did not become obvious until after two years of mulch treatment.

The response of *Aira caryophyllea* was the reverse of that shown by *Bromus mollis*. Large amounts were present with no mulch while the least occurred where there was maximum mulch. Only slight tendency toward this trend appeared in 1953. By 1954 it was definitely shown between the two extremes of treatment. In 1955, the percentage was very much higher where mulch was absent than on the other treatments and at the same time it was low on the 4 treatments with the most mulch.

All the other grasses including *Festuca dertonensis, Briza minor, Gastridium ventricosum, Bromus rigidus,* and a few others did not show significant differences due to mulch treatment. However, by 1955, they too seemed to be following the trend described for *Aira caryophyllea*. Perhaps they will respond with treatment in additional years. Aside from *Festuca dertonensis,* they made up a small proportion of the stand.

Legumes

The legumes as a group did not contribute over 17 per cent of the composition in any year and in 1954 they were under 3 per cent. Consequently, the sample was small and trends due to mulch treatments were over-shadowed by yearly differences. However, the extremes in mulch treatments seemed to result in low percetnages while small amounts of mulch allowed the greatest development of legumes. *Trifolium ciliolatum* and *Lupinus bicolor* each made up about one-third of the composition and 8 other species contributed the additional one-third.

Erodium botrys

Treatment differences were significant at the 5 per cent level. However, only two treatments were different from the others. An intermediate mulch treatment was low in all years and the most mulch gave the highest percentage of *Erodium*. When the composition percentages for 1955 were adjusted by regression to a constant percentage for 1952, no significant differences were found between treatments. Those treatments which had large amounts of *Erodium* in 1952 also were high in 1955. Thus, treatment of mulch in the manner of this experiment had little effect on the percentage of *Erodium* in the composition.

Other broadleaved species

Baeria chrysophylla responded quickly and markedly to the mulch treatment. By the end of

FIG. 3. These three one-inch thick strips of vegetation illustrate some of the differences in percentage botanical composition and height found with manipulation of mulch. The upper occurred only where all mulch had been removed. *Baeria chrysostoma*, *Pentachaeta exilis* and *Aira caryophyllea* were the abundant plants. The middle strip also shows short growth but a composition of small grasses, legumes and *Erodium botrys*. The tallest growth and importance of *Bromus mollis* where the greatest amounts of mulch occurred are illustrated in the lower strip.

the growing season following the first mulch treatments, this plant showed highly significant differences from a large percentage in the bare treatment to a low percentage with greatest mulch. The trend between the two extremes was obvious on the ground as well as in the data. When the golden-colored flowers were open, the plot boundaries and treatments were conspicuous by varying amounts of the plants. *Hypochoeris glabra, Linanthus ciliatus, Pentachaeta exilis, Orthocarpus erianthus,* and *Galium parisiense* exhibited much the same tendencies as *Baeria* although to a lesser degree.

When all of the broadleaved plants except legumes and *Erodium* were considered as a group, it was found that increasing amounts of mulch resulted in a decreasing proportion of broadleaved plants.

In summary of the effect of mulch on botanical composition, several points need to be made. *Erodium* was found not to show a significant relationship between the percentages at the beginning and end. It would seem that amounts of it had little relationship to the mulch treatments. Two plants, *Bromus mollis* and *Baeria chrysostoma* were very sensitive to the treatments. *Aira caryophyllea* and *Hypochaeris glabra* were indicative also but not as sensitive as the first two.

The data indicate that mulch has a direct effect on composition. It may also have an indirect effect through competition. For example, plants of *Bromus mollis* were in greatest numbers with most mulch and *Baeria chrysostoma* was least. *Baeria* might have responded differently if the *Bromus* had been absent.

Vegetational Differences Between Years

The effects of the yearly march of weather on vegetation has been widely recognized. It is very striking in the California annual type and most field studies must recognize this variable. Starting from seed each fall, as they do, makes these annuals very responsive to differences in environmental conditions. They must be able to germinate, grow, and produce seed each year. Since no two species respond alike, there is little wonder that the vegetation takes on different appearances from one year to the next. Table IV shows some of these differences but it must be recognized that effects of mulch are cumulative so that the data must be interpreted accordingly.

One of the most striking changes was the large proportion of *Erodium botrys* in 1955 (Figure 4). This plant has a large seed, germinates quickly when moisture arrives, and develops a long tap root in a few days. Something over an inch of rain in the last of August, 1954, fostered germination at that time. Even though the next rain did not come until October 15, many *Erodium* plants survived. With the advent of the later rains, another crop of seedlings appeared. For several months during the winter two age groups of *Erodium* were present. The winter of 1954-1955 was an especially cold one, total rainfall was light, and there was a long period in early spring without rain. The period of flush growth came in late April and early May and was a short one. Whatever the causes, *Erodium* produced an exceptionally large amount of herbage. It contributed much more to the percentage composition than in any previous year irrespective of mulch treatment.

The small annual legumes did not germinate with the August rain in 1954. However, by the end of the growing season these plants were much more evident than in previous years. In general terms, 1955 was a good year for clover and 1954 was a poor year. Differences among the legume species were not evident. All were either abundant or rare in the different years.

On a percentage basis, when some components of the vegetation increases others must decrease. There were fewer grasses in 1955 even though they were abundant in 1954 (Figure 5). Other types of broadleaved plants were about the same in 1954 and 1955 and in both years less than in 1952 and 1953. The small percentage of *Bromus mollis* in 1952 is probably a result of heavy grazing before the experiment began.

In general terms, 1955 was a good year for *Erodium* and legumes and a poor one for grass. Grass did relatively better from 1952 to 1954 and 1952 could be considered a fair clover year.

Analysis of variance after angular transformation of the percentages showed highly significant yearly differences within the 5 categories in Table IV and for *Aira carophyllea, Festuca dertonensis, Baeria chrysostoma, Hypochoeris glabra,* and *Linanthus ciliatus*. The F ratios ranged between 8.20 and 35.28. Variance was not calculated for other species because they were too scarce for the samples to be adequate.

Rate of Plant Development

Ordinarily in the California annual type, germination begins immediately following the first fall rain of about half an inch. Precipitation fell nearly every day between October 10 and 19, 1953, for a total of 1.73 inches in the period. By November 4, the heights attained by the new plants were very obviously different on the various mulch treatments. *Bromus mollis* was found to average 0.81 inch in height where there was no mulch and 2.98 inches on the treatment with the most mulch. The heights on intermediate mulch treatments were between these two extremes. The correlation coefficient between the weight of mulch on August 27, 1953, and the heights of *Bromus mollis* was 0.718 which is significant at the .05 level. It indicates a positive relationship between amounts of mulch and plant development.

The observed differences in heights of *Bromus mollis* on November 3, 1953, seemed to be closely related to the height of stubble or position of the mulch. A highly significant correlation coefficient of 0.943 was found between the heights and stubble of *Bromus mollis*. Thus, position of the mulch is an important factor as well as the amount.

Height of Vegetation

The height of plant materials above the ground was ascertained by measuring the distance between the first hit of the pins and the soil surface. This is not a measurement of maximum height of plants but an attempt to obtain a height of vegetation. If the vegetation is tall or short, this type of measure should indicate the differences. One advantage of the sample is that it is objective and relatively free from personal bias. Another is that the understory plants are included

FIG. 4. On April 26, 1955, the proportion of grass to broadleaved herbs was low on all plots and the vegetation was shorter than in other years. *Erodium botrys* was the highest of any species in percentage composition. The large bunches are *Stipa pulchra*.

FIG. 5. On April 27, 1954, the proportion of grass to broadleaved herbs was high on all plots. The vegetation was taller than in other years of the study.

in the determinations. The measurements are on the same plants that are tallied as hits to compute botanical composition. Height of plant materials is a characteristic of vegetation and measurements of height should have intrinsic value.

The averages of all heights by treatment are shown in Table V. Considerable and significant differences occurred between years. In 1954, the grasses grew very well and their height is reflected in the average for that year. *Erodium botrys,* a plant of low stature, was relatively more important in 1955, a fact indicated by the low average height.

TABLE V. Average heights in inches of vegetation by treatments and years

Treatment	4-29-53	4-26-54	4-26-55
1	2.84	3.29	1.14
2	3.08	4.10	1.68
3	3.15	3.78	1.71
4	3.12	3.95	1.59
5	2.95	3.90	1.88
6	3.12	4.21	1.58
7	2.97	4.56	1.97
8	3.55	5.90	2.33
Average	3.10	4.21	1.74

Treatment differences within 1954 and 1955 were highly significant. In all three years, the treatment without mulch had the lowest vegetation while the tallest vegetation was where the most mulch occurred. Variations among Treatment 2-7 generally were not significant. Observations during the growing season led to a general conclusion that the height of plants at any time was at least in part dependent upon the height and position of the mulch. The fact that stubble heights were 0 for Treatment 1, 1.25 inches for Treatments 2-6, 2.5 inches for Treatment 7, and about 6 inches in Treatment 8 would indicate a positive relationship with the heights shown in Table V. Position and height of mulch has a direct influence on growth of plants as well as on yield and ground coverage.

Ground Cover

Ground cover or coverage is here defined as the percentage of the soil surface covered by living plants. It has been referred to frequently in range management work as density. The concept is an important one and is commonly used in the description of vegetation. Coverage data were obtained by the point system as simply the percentage of pins which hit living plants.

In this experiment coverage proved to be a very insensitive measure of the effects of mulch (Table VI). Location differences within years were quite pronounced and were indicated by highly significant row and column effects. The variance within treatments was also significant but the between treatment differences were not. Yearly differences in coverage were of the greatest magnitude and highly significant. It would appear that differences in coverage in the kind of vegetation used in this experiment were related more to location within any one year and to compositional differences between years than to compositional differences which resulted from the different treatments. If this can be extended to the entire California annual type, then coverage or density as such becomes of little value as a guide to range condition and for evaluating grazing practices. On the other hand, the coverage by species can be used to compute percentage botanical composition quite effectively.

TABLE VI. Percentage of the soil surface covered by living plants

Treatment	1952	1953	1954	1955	Average
1	82.5	69.4	79.4	50.0	70.3
2	76.2	67.5	85.6	63.1	73.1
3	85.0	59.4	83.8	61.3	72.4
4	87.5	70.6	81.9	65.6	76.4
5	72.5	68.7	89.4	57.5	72.0
6	82.5	73.7	81.3	59.4	74.2
7	82.5	62.5	86.3	68.1	74.6
8	85.0	66.9	73.8	61.3	71.8
Average	81.7	67.2	82.7	60.8	

Damage by Frost

Damage to seedling plants by frost heaving is often observed in California (Biswell, *et al.* 1953). Several times each winter, the various treatments were examined for this type of damage. In no case was frost heaving observed where the soil had a cover of mulch. On the other hand, heaving was observed on several occasions where there was no mulch. Legumes especially and occasionally individuals of the other species, except *Erodium botrys,* were found on the bare plots that had been heaved by frost. This factor undoubtedly contributed to the changes in composition on the bare plots as well as the lack of mulch.

Erosion and Runoff

The plots were examined periodically for evidence of runoff and erosion. Runoff undoubtedly occurred from the plots when the rainfall was intense but no evidence of erosion appeared on any of the plots that had mulch. The bare plots showed erosion in early fall following the first rain especially if that rain was intense (Figure 6). Within 3 or 4 weeks after the soil was wet, the new plants had grown enough to protect the soil and no further evidence of erosion was noticed. For the conditions of this experiment mulch was important in reducing erosion only until the new crop of plants had covered the soil.

FIG. 6. Small terraces of soil and fine mulch washed from a bare plot during a storm of high intensity on October 18, 1953. Movement of materials was not obvious on the plots with a mulch cover.

DISCUSSION

On the basis of this experiment, there seems little doubt that the amount and position of mulch in the California annual-type grassland are important factors which influence botanical composition and speed of plant growth. Since the latter two items are useful in the evaluation of the influence of grazing, determinations and interpretations of mulch effects should also be of value. The phase of range management most likely to benefit is that involving determination of forage utilization by livestock and the establishment of proper use standards. The concepts of current forage utilization, standards of proper use, and mulch are closely related. Utilization refers to the amount or percentage of current growth actually removed by the grazing animals. Proper use means utilization that will allow for continued high forage production. The portion of the herbage crop that remains after grazing on grasslands is mulch.

In studying and measuring utilization, the question arises as to whether emphasis should be placed on the portion of the forage eaten by livestock or the portion which is uneaten. Unfortunately, consumed forage cannot be measured directly. Therefore, attempts to measure the animal diet usually depend upon differences of measurements taken before and after grazing or under grazed and ungrazed conditions and upon conversion techniques. Inaccuracies seem to be inherent in these techniques so none of them have been accepted entirely.

The problem of determining the diet of a grazing animal is worthy of attention *per se*. One should know what plants in what proportion constitute the feed. These are important in the animal as well as in the plant aspects of range management. However, emphasis in the concept of utilization may be given in another way as illustrated by the question: How much plant material must remain to insure maintenance of forage production? This is conveyed in proper use standards but they are usually given in terms of the percentage of the crop which must remain after grazing. The results of this experiment suggest that it is the absolute amount and position of the material itself that is important rather than the percentage of the crop for the California annual type.

If the emphasis were put on the amount of plant residue needed to maintain production, then the measurements become straightforward. In this approach the procedure would be to describe proper use and adjust stocking on a basis of the material remaining (mulch) rather than on the material removed. The standards of proper use can be detemined by experimental procedures in direct terms such as weight of mulch per acre and percentage of soil covered at certain times of year. The standards would be the amounts of mulch needed to maintain production, promote ideal botanical composition of the ranges, and provide for adequate soil condition. Once these are determined, the field application becomes a direct sampling process. This approach was suggested by Dyksterhuis and Schmutz (1947) and expanded by Hyder (1954) on a basis of logic.

Forage plants in the California annual type are small, very close together, and annual. The vegetation contains many species which vary greatly in percentage composition from year to year. They also respond rapidly to varying amounts of mulch present at the beginning and during the growing season. The conventional methods of determining proper use and measuring utilization in other vegetational types are difficult to use. For these reasons, the "mulch" approach to help guide management of the California annual type may have considerable merit.

The finding that position or height of mulch is a factor in promting plant growth suggests that grazing should not be excessive and that animals should not be placed on a range of the California annual type in large numbers in order to remove all the harvestable forage in a short time. Grazing over a long period of time will allow animals to select the most palatable kinds of plants and plant parts. The mulch remaining after grazing would be composed largely of coarse stems and other materials high in fiber. Thus, moderate yearlong grazing would allow the animals to harvest the best forage and at the same time leave a favorable mulch cover.

Summary

1. Amounts and position of natural mulch were manipulated according to 8 treatments and 8 replications for a period of 4 years. Yearly production of herbage was on oven-dry weight basis determined by sampling square-foot plots. Botanical composition, ground coverage and height of plant materials were determined by the point system.

2. A total of 46 species was found in the study area. Sixteen of them were alien and 40 were annual. Six species that were both alien and anannual contributed between 67 and 84 per cent of the composition during the 4 years of the study.

3. A perennial bunchgrass, *Stipa pulchra,* increased in numbers from none to 612 plants within the exclosure between 1952 and 1955.

4. Amounts of mulch in the different treatments varied between zero and nearly 5,000 pounds on an acre basis. Not all of the mulch decomposed each year so there was a gradual accumulation from 1952 to 1955. The percentage increase was relatively greater where a larger proportion of current growth was left on the plots than where small amounts remained. The increase in percentage of the soil surface covered with mulch in each April from 1953 to 1955 also indicated accumulation of mulch.

5. With increasing amounts of mulch on the soil immediately before the fall rains, there was an increase in herbage production the following spring. This relationship is expressed by the regression equation $Y = 1214 + 0.354X$ for production within the 1,200 to 2,400 pound range.

6. *Baeria chrysostoma* responded quickly to the mulch treatment and after 1953 it was very abundant with no mulch and absent where mulch was the heaviest. *Aira caryophyllea* reacted in a similar fashion except it did not show significant differences between treatments until 1954 and the trend was still developing in 1955. Several other grasses and broadleaved herbs followed these same trends although to a much less degree.

7. *Bromus mollis* was the only plant that increased a significant amount in percentage composition with the heaviest mulch treatments. It is the species which contributed most to the high production.

8. The legumes and several additional grasses including *Festuca dertonensis* were most abundant on intermediate treatment. However, these differences were not significant.

9. Differences in the proportions of *Erodium botrys* due to treatment were not conclusive. However, this species and all others tested showed highly significant differences between years. Studies on the natural vegetation in the California annual type should include a measure of the variation resulting from different yearly environments. Otherwise, these may overshadow or confuse the differences due to treatments.

10. The proportion of the soil surface covered with moss varied significantly between years and to a less extent between treatments.

11. The height reached by *Bromus mollis* in the fall after the first effective rain and before cold weather was dependent upon the amount of mulch and the height of stubble (position of the mulch).

12. The average height of plant materials was determined by measuring the height of the first hit of the points above the soil surface. Significant differences in height of vegetation occurred between years and between treatments within 1954 and 1955. Both yearly and treatment differences in height undoubtedly reflect the differences in botanical composition.

13. The total percentage of ground covered by vegetation was related more to differences between years and and between locations than it was to differences in botanical composition between treatments.

14. Soil movement during the first intense fall rains and frost heaving were observed only on the plots where all mulch was removed each year.

15. The use of mulch in the appraisal of proper utilization of the annual range by livestock is discussed.

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USE OF OFFICIAL WEATHER DATA IN SPRING TIME—TEMPERATURE ANALYSIS OF AN INDIANA PHENOLOGICAL RECORD

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INTRODUCTION

Many statements might be quoted stressing the limitations of official U. S. meteorological records for ecological use. Also, the method of summation based on these or similar data has seldom found favor among ecologists, although it has recently proved successful in predicting the harvest date of peas (Sayre 1953) and is being used by truck-farming corporations for various crops. Nuttonson (1955) reviewed the literature, largely Russian, on wheat phenology, and extensively applied the conventional "remainder-index" method of summation, based on monthly means, to winter and spring wheat. Andrewartha and Birch (1954) criticized the summation idea, on theoretical grounds, for animals.

It seemed to the writers that new methods of treating Weather Bureau climatological records might be discovered which would give the massive, geographically widespread, long-continued, and readily accessible data an increased value for a number of purposes in plant and animal ecology and in agronomy. With this object in view, the statistical study here reported was undertaken jointly by the authors, representing pure and applied science fields, respectively.

The late Charles C. Deam, author of "The Flora of Indiana," kept careful records of the dates of first spring flowering for the plants in his private arboretum and garden at Bluffton, Indiana, from 1920 through 1952. Records are meager for the first few years while plants were being established, but *Sanguinaria canadensis* is recorded for 30 years and some others almost as long; these are therefore remarkable data compared with other American phenological records of native species. Other features are the authoritative identification and the fact that, for most of the woody plant species, all the annual dates refer to the same individual specimen, and to a clone for many of the herbs. This is the first published report involving the records, except for a mention of temperature effects on *Cercis canadensis* L. in a paper by Plummer and Lindsey (1955).

The Deam Arboretum comprised 3 acres at the outer portion of the Wabash River flood-plain at the west edge of Bluffton, Indiana. The soil type is Genessee silt loam. Dr. Deam recorded the date of first flower-opening at about 8:00 a.m. each morning when at home; he made no climatological records. The Bluffton Water Works, adjacent to the Arboretum on the east, initiated a meteorological station in cooperation with the U. S. Weather Bureau and obtained unbroken records for 1949 through 1952. For the years 1920 to 1940, good records from another weather station at Bluffton are available. However, because satisfactory weather records were not made at Bluffton from 1941 through 1948, the phenological records from this period have not been utilized for the principal analysis in the present paper. The plant names herein are those used by Deam (1940).

The long-continued meticulous observations by Dr. Deam and his kindness in furnishing his records for analysis have made this report possible. Word of their existence and help in obtaining them had come from Prof. Daniel DenUyl. Prof.