

# Fertilization and Management Implications on California Annual-Plant Range

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## Highlight

The results from the first three years of a study at the San Joaquin Experimental Range on the effect of sulfur and sulfur-plus-nitrogen on management of annual-plant range are reported. Fertilizer increased production, especially in herbage yield and grazing capacity. Some effects these results may have on the costs of grazing cattle, especially in the green-forage season, are discussed.

Herbage yield on many annual-plant ranges in California has been increased by fertilizing with sulfur or sulfur-plus-nitrogen. The increase from use of sulfur has been as much as 200%; sulfur-plus-nitrogen could bring even greater increases. When herbage yield is increased, grazing capacity generally increases.

Wagnon et al. (1958) found that daily gains in steers also increased on sulfur-fertilized ranges.

Sulfur deficiency has been found in more than half the counties in California. And nitrogen deficiency is assumed to be at least as widespread (Martin, 1958). But as researchers and ranchers have become more experienced in using fertilizers, they have found that gains have brought more problems along with more returns.

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Increased returns are mainly from the greater number of live-stock that can be grazed. To graze the maximum number of animals, a rancher must know in advance how much herbage will be produced. He must consider land values before deciding whether to fertilize; he must also consider his ability to predict weather, and decide how often to fertilize. It is possible that buying or renting more land may be less expensive than buying and applying fertilizer.

Some information on managing and integrating fertilized and unfertilized annual-plant range is now available from a study started in 1959 at the San Joaquin Experimental Range, near O'Neals in the central Sierra Nevada foothills of California. The Experimental Range is maintained by the Pacific Southwest Forest and Range Experiment Station of the Forest Service, U. S. D. A. This paper reports results from the first 3-year fertilization cycle, completed in 1962. Some preliminary results were reported by Woolfolk and Duncan (1962).

### The Study

The study design includes twelve separate range units at the Experimental Range. Hereford yearling calves—heifers the first year and steers the second and third years—were used in the study (Fig. 1). Fertilizer was applied in the fall of 1958 on the range units that were to be grazed in the dry-forage season, and in the fall of 1959 on the range units to be grazed in the green-forage season. Four range units were fertilized with gypsum to furnish 60 lb/acre of sulfur. Four others were fertilized with a mixture of ammonium sulfate and ammonium nitrate to furnish 60 lb of sulfur plus 80 lb/acre of nitrogen. The remaining four units were left unfertilized.

The cattle started grazing on dry summer feed, wintered on adjacent unfertilized range, and finished on green feed the next spring. Half the range units were stocked to capacity in June or July to obtain moderate use of the herbage by the end of the



Fig. 1. Yearling steers grazing green annual-plant herbage on unfertilized range at the San Joaquin Experimental Range.

dry-forage season, in October or November. The other range units were similarly stocked during the green-forage season, usually the first part of February through early June. In this report, these two forage seasons will be referred to as the dry and green seasons, and the range units grazed during each as dry- and green-season units, respectively.<sup>2</sup>

Precipitation at the San Joaquin Experimental Range from 1934 through 1962 averaged about 19 inches per year, almost all rain. About  $\frac{3}{4}$  of the total fell during the period from December through March (Fig. 2). Only the 1961-62 rainfall was average or better compared with the 29-year average (Fig. 3).

Past experience has shown that most plant growth occurs when mean daily temperature is above 50°F. Average daily temperature in March generally is above 50°F, but in 1961 and 1962, it was not until April that the average daily temperature rose above 50.

<sup>2</sup>For statistical analysis the study was set up as a split plot with two blocks. The main plot effects were between forage seasons because of the crossover grazing program described by Woolfolk and Duncan (1962). The sub-plot effects were due to fertilizer treatments.

### Vegetation Results

Even though rainfall was below the long-term average except in the 1961-62 weather year, herbage production exceeded the 1,650 lb/acre long-term average in both 1960 and 1962. In general, if rainfall is below average, total herbage yield is expected to be below average. This was generally true of herbage yield, except in 1960 when it was 13% above average even though rainfall was 18% below average. Apparently spring rainfall in 1960, along with slightly warmer-than-average March temperatures, made up for the over-all lack of rainfall. In 1962 yield was 11% above average; rainfall was 9% above average.

Response of total herbage production to sulfur fertilizer was not remarkable at any time. First-year increase was less than 200 lb/acre in both the dry-season units in 1959 and the green-season units in 1960 (Table 1). Response in the second and third years after application was greater than in the first year, but still was lower than that reported by

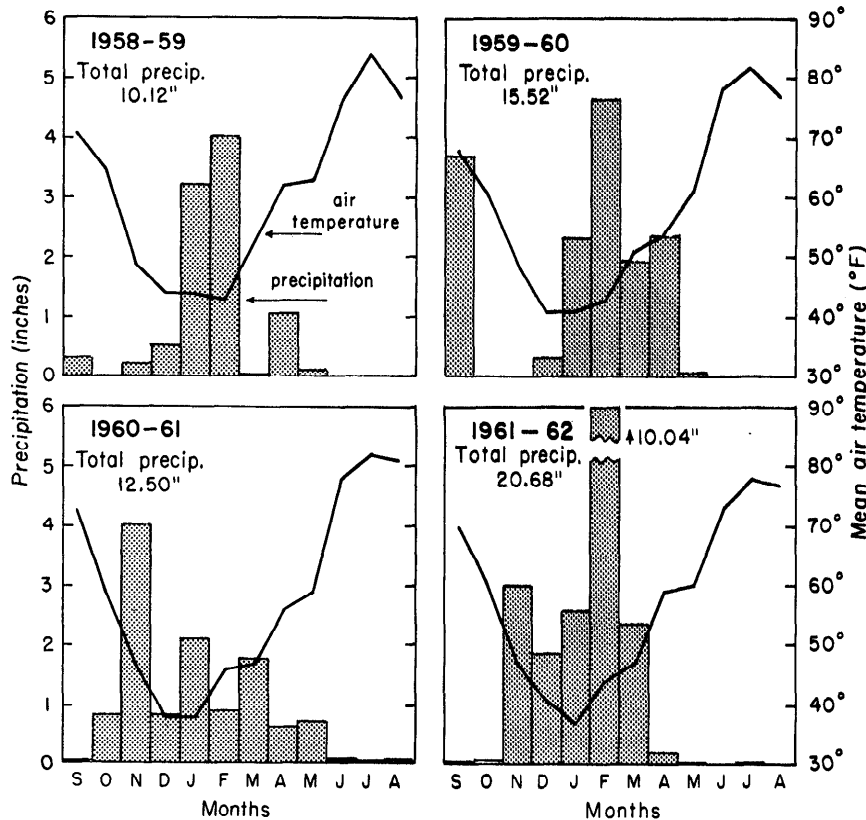


Fig. 2. Monthly rainfall and mean air temperature, September through August, at the San Joaquin Experimental Range, 1958-62.

Table 1. Yield of annual-plant herbage, in lb/acre air-dry, San Joaquin Experimental Range (1959-62).

Year	Fertilizer (dry-season units)			Fertilizer (green-season units)		
	None	Sulfur	Sulfur+ nitrogen	None	Sulfur	Sulfur+ nitrogen
1959	692	884 <sup>ns</sup>	2,513 <sup>**</sup>	—	—	—
1960	1,662	2,066 <sup>*</sup>	3,485 <sup>**</sup>	2,074	2,179 <sup>ns</sup>	4,906 <sup>**</sup>
1961	1,307	1,529 <sup>ns</sup>	2,020 <sup>**</sup>	1,477	1,859 <sup>ns</sup>	2,235 <sup>**</sup>
1962	—	—	—	1,829	2,345 <sup>*</sup>	2,712 <sup>**</sup>

Table 2. Percent weight composition of annual-plant herbage at the San Joaquin Experimental Range (1959-62).<sup>1</sup>

Plants	Fertilizer <sup>2</sup>											
	1959			1960			1961			1962		
	None	S	S+N	None	S	S+N	None	S	S+N	None	S	S+N
Grasses <sup>3</sup>	58	71	71	26	35	45	35	42	59	58	54	64
Forbs:												
Filaree	39	26	27	63	58	49	55	47	38	22	21	23
Clover	1	1	1	1	1	( <sup>4</sup> )	2	7	2	8	12	7
Other	1	2	1	10	7	6	7	4	1	12	12	6

<sup>1</sup> Except for 1959 and 1962 these data were calculated from the combined herbage production on units grazed in the dry- and green-forage seasons. The 1959 composition was calculated from the units grazed in the dry season and the 1962 composition from the units grazed in the green season.

<sup>2</sup> S=sulfur fertilizer, S+N=sulfur-plus-nitrogen fertilizer.

<sup>3</sup> Grasses include all true grass species plus small amounts of grasslike species.

<sup>4</sup> Less than 0.5 percent.

Bentley et al. (1958). Increase per year averaged about 270 lb on the dry-season units and 300 lb on the green-season units.

What is most striking about the units fertilized with sulfur-plus-nitrogen is the comparatively high yield in each year, including 1959. A less obvious but important comparison was the effect of dry weather on the carryover of sulfur-plus-nitrogen fertilizer. On the dry-season units fertilized with sulfur-plus-nitrogen, yield was 1,820 lb/acre higher than on the unfertilized units in both of the first two years. On green-season units, herbage yield was 2,830 lb/acre more than on unfertilized units in 1960, but only 760 lb more in 1961. The third-year increase was about 700 lb/acre on the dry-season units and about 900 lb on the green-season units. The average increase from sulfur-plus-nitrogen for three years was about 1,400 and 1,500 lb/acre on the dry-season and green-season units, respectively.

Botanical composition was changed drastically in 1960 by poor rainfall distribution the preceding fall and winter. In 1959 herbage composition was roughly 58% grass and 40% filaree (*Erodium* spp.) on the unfertilized units (Table 2). This is a fair balance of grass and filaree. In 1960 the balance was

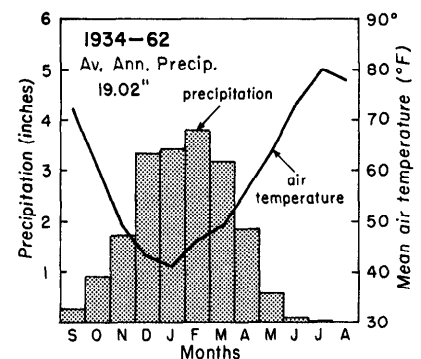


Fig. 3. Average monthly rainfall, 29 years (1934-62), and mean air temperature, 28 years (1935-62), September through August, at the San Joaquin Experimental Range.

upset—26% grass and more than 60% filaree. Reppert and Duncan (1960) have suggested that a fall drought, which lasted for more than three months in 1959 and followed an early storm that produced 3.75 inches of rain (Fig. 1), probably caused these unusual composition percentages. Finally, in 1962 there was a favorable balance of 58% grass and 22% filaree. Fertilizer apparently decreased the effect of the long fall drought in 1959. Even in 1960, grass made up 35 and 45% of the weight on the units fertilized with sulfur and sulfur-plus-nitrogen.

Clover response to sulfur did not begin to approach the proportions reported by Bentley et al. (1958) and Green et al. (1958) until 1961. This lack of response was apparently the result of low rainfall or poor rainfall distribution or both.

#### Grazing Seasons and Grazing Use

The animals started grazing on dry-season units when most of the plants were dry. They were not moved to the wintering unit until herbage use was satisfactory or the herbage was severely leached by fall rains. During the winter some new plant growth was available along with leached old growth and supplemental feed. The animals were put into the green-season units when plant growth became sufficient to produce gain without supplemental feed. The starting dates of green-season grazing varied between treatments and between years, depending on fertilizer and weather.

In each year of the study, more days of grazing were provided by fertilized range than by unfertilized range (Table 3). The amount of grazing use furnished by dry- and green-season units depended on the amount of herbage that cattle could use without overgrazing. By using extra animals, we attempted to obtain equal use on all units by the

**Table 3. Animal-days grazing per acre by yearling cattle at the San Joaquin Experimental Range (1959-62).**

Year	Fertilizer (dry-season units)			Fertilizer (green-season units)		
	None	Sulfur	Sulfur+ Nitrogen	None	Sulfur	Sulfur+ Nitrogen
1959	7.8	8.5 <sup>ns</sup>	28.1 <sup>**</sup>	—	—	—
1960	19.7	31.7 <sup>ns</sup>	57.3 <sup>**</sup>	20.4	40.5*	69.3 <sup>1**</sup>
1961	29.6	41.8 <sup>ns</sup>	52.3*	24.8 <sup>1</sup>	43.4*	52.2 <sup>1*</sup>
1962	—	—	—	23.1	40.2 <sup>ns</sup>	45.8*

<sup>1</sup> Adjustments in unit boundaries and correction of measurement errors changed these statistics since first published (Woolfolk and Duncan, (1962), but did not affect prevailing trends or resulting comparisons.

end of the respective grazing seasons. We counted the number of steer-days—heifer-days in 1959-60—and calculated the actual animal-days use per acre. For the dry and green seasons combined, an average of 21 days/acre of grazing per year was provided from the unfertilized range, 34 days from the sulfur-fertilized range, and 50 days from the sulfur-plus-nitrogen-fertilized range. To check the equality of use, we estimated the amount of residue remaining in each unit after grazing was completed. The differences between units were small in any single year.

Grazing use can be a valuable criterion for evaluating the effect of a change in a range operation. It is especially sensitive to the amount of feed available. In the annual-plant range type, differences in the amount of feed resulting from some treatment can be more important than differences in quality of feed, especially in the green season. Most of the herbaceous species are high quality for at least part of the growing period.

The amount of grazing produced in 1959 was lower than we hoped for, but the fertilizer applied in 1958 was not lost. The response in 1960, and again in 1961, demonstrated that the effects of sulfur or sulfur-plus-nitrogen extend beyond one year. The sulfur-fertilized units grazed during the dry season produced from one additional day/acre in 1959 to 12 additional days in 1960 and in 1961. The sulfur-plus-nitrogen-fertilized units produced

20 more days grazing per acre than the unfertilized units in 1959; 38 more days in 1960; and 23 more days in 1961.

The extremely dry 1958-59 season was reflected in days of grazing in 1959 and in herbage yield. The most encouraging result that year was the grazing produced by the sulfur-plus-nitrogen-fertilized units. Less than 8 days grazing per acre were produced on the unfertilized units and only 8.5 days on the sulfur-fertilized units. The 28 days grazing per acre from the sulfur-plus-nitrogen-fertilized units were nearly 4 times that from the unfertilized units; still, the 28 days were only about what we normally would expect from an unfertilized range.

The grazing produced by the unfertilized green-season units did not vary among years nearly as much as did the grazing produced by the unfertilized dry-season units (Table 3). Weather is the basic reason for less difference among the green seasons. A single dry year accounted for the extreme variation among the dry seasons: 22 days/acre between the best and poorest. There were no outstandingly dry or wet years among the three green seasons; consequently, less than 4.5 days/acre difference separated the best from the poorest green season.

The same reasoning applies to the variation in the amount of grazing produced on the sulfur-fertilized units. The difference was 33 days grazing per acre between the best and the poorest

dry season, but only 3.5 days difference for the same comparison among green seasons. The sulfur-plus-nitrogen-fertilized green-season units produced 69 days/acre in 1960; 52 days in 1961; and 46 days in 1962. This is the way we expected sulfur-plus-nitrogen fertilizer to affect grazing capacity.

Part of the increased grazing capacity on the sulfur-plus-nitrogen-fertilized units resulted from earlier range readiness. In both 1960 and 1961 animals were turned in 25 days earlier than on the other units. Increased early grazing capacity could be one of the most valuable aspects of sulfur-plus-nitrogen-fertilized range. The range was ready for grazing when the herbaceous plants developed enough to feed the animals adequately. Even at these early dates, February and January in 1960 and 1961, little trampling damage resulted because most of the soils dry rapidly.

#### Cattle Performance

So far in this study, total gain per animal has averaged from more than 400 lb in the first year to about 260 lb in the third year. The cattle used the first year (1959-60) were heifers whose average starting weight was 464 lb/animal. The average starting weights of the steers were 414 lb in 1960 and 409 lb in 1961. The heifers also started out as older animals than the steers did, and they stayed on the range two to three weeks longer. These are three of the reasons the animals gained considerably more during the first year than in either of the other two years. The quality of the herbage for feed, discussed below, was another reason for better gains the first year.

At the beginning of each study year in June or July, the animals were grouped so the groups would differ only slightly in average weight. The range of weights in each group was also

kept as small as possible. Each group was then assigned to a unit. In 1959 the average starting weight of the heifers in the unfertilized units was 462 lb; in the sulfur-fertilized units, 463 lb; and in the sulfur-plus-nitrogen-fertilized units, 467 lb. In 1960 the average starting weight of the steers was nearly 414 lb in each of the units. In 1961 the average starting weight of the steers was 410, 410, and 406 lb/animal on the unfertilized, sulfur-, and sulfur-plus-nitrogen-fertilized units, respectively.

Table 4 shows the difference among animal weight gains. Much of the difference among dry-season units in each year is probably a response to the botanical composition (Table 2) and nutritive quality of the herbage rather than to total yield. As the relative amount of grass and clover increases and forbs other than clover decrease, the cattle weight gain in the dry season should increase. Data from this study seem to support this hypothesis. Except for clover, forbs tend to become brittle and lose their leaves and seed in the first or second month of the dry season. During the same

period, grasses also become dry, lose much of their seed, and nutritive quality, but tend to stay pliable and keep their leaves. Clover seems to stay green later than either grasses or other forbs.

Live-weight gain per animal in 1959-60 was materially higher on the sulfur-plus-nitrogen-fertilized units than on the other units. The difference in gain on the dry-season units was greatest—more than 70 lb/animal higher than on the unfertilized units. The difference in gain on the green-season units is important, but may be misleading. The green season in each of the first two years was 25 days longer on the sulfur-plus-nitrogen-fertilized units than on the other units. The daily gain on the sulfur-plus-nitrogen-fertilized green-season units was actually lower than on the other units in 1960 and also in 1961. Otherwise the cattle performed equally well on all of the green-season units.

During the wintering period the cattle in this study gained considerably in total weight, but daily gain was below a pound. The first herd gained about 0.7 lb/day, the second 0.8 lb, and the third 0.4 lb/day. To maintain these winter gains, a cottonseed meal-salt mixture was fed free choice each winter. Depending on the weather and the amount of green forage available, the amount of meal eaten varied. Generally the cattle ate from 1.1 to 1.6 lb/day per head.

#### Implications

The obvious conclusion from this study is that sulfur-plus-nitrogen fertilizer caused herbage and cattle production to increase. Sulfur alone also caused some increase but by a much smaller amount. Additional production, however large, implies new problems in range management. Some of these implications may be considered within the scope of this paper.

**Table 4. Average live-weight gain, in lb/animal, for yearling cattle by forage season, San Joaquin Experimental Range (1959-62).**

Year and fertilizer <sup>1</sup>	Forage seasons			Total
	Dry	Winter	Green	
1959-60				
None	65	116	189	370
Sulfur	83	134	171	388
S+N	136	116	210	462
1960-61				
None	-2	98	214	310
Sulfur	-9	110	205	306
S+N	2	101	220	323
1961-62				
None	33	65	154	252
Sulfur	42	67	159	268
S+N	56	62	149	267
Averages				
None	32	93	186	311
Sulfur	39	104	178	321
S+N	65	93	193	351

<sup>1</sup>S+N = Sulfur-plus-nitrogen fertilizer.

We have placed major emphasis on animal-days of grazing produced by the range units. Granted, there were some differences in average gain per year per animal among the units.

Live-weight gain was greatest on range units fertilized with sulfur-plus-nitrogen and was particularly noticeable on the dry-season units. In one year, the cattle on such units gained more than 100 lb during the dry season. Fertilizing range with sulfur-plus-nitrogen cannot be justified solely by this amount of gain for one out of three years. Apparently the cost of fertilizing with sulfur-plus-nitrogen for dry-season use must be justified by the need to provide for a source of additional or emergency forage. An example of this kind of need occurred as a result of the 1958-59 drought. A fair-sized herd could have been maintained by a relatively small amount of fertilized range. Fertilizing for dry-season use may have more advantages that are not yet apparent. The period covered here, only three years, is questionable as being representative — considering the weather. Also, these results apply only where application of fertilizer is once every three years at the rate we used.

The greatest differences among fertilizer treatments occurred in the green-season units. Consequently the rest of this discussion will deal mainly with the green seasons. Even these differences mostly affected grazing capacity rather than animal gain. There should be little difference in animal gain, provided an adequate amount of forage is available at all times during the green season.

The seemingly obvious conclusion is that sulfur-plus-nitrogen fertilizer gives the best results because grazing capacity is highest where this fertilizer is used. But the relationship between the cost of fertilizing and the amount

of additional grazing obtained may modify or even change the conclusion. Certainly some consideration of costs is needed to strengthen the usefulness of the information.

We do not intend to make an economic analysis of the data presented. But we can show how our costs may affect a fertilizer program. As stated earlier only two rates of fertilizer were applied, 0 and 60 lb of sulfur or 60 lb of sulfur plus 80 lb of nitrogen. The rates were based on the results of earlier work done at the San Joaquin Experimental Range (Green and Bentley, 1954; McKell et. al., 1960).

Recognizing these limitations, we used the information from the studies to evaluate the cost of grazing on these particular range treatments. The information, consisting of averages from the data presented earlier, was as follows:

1. Average length of the green season in days:  
 Unfertilized units ..... 96  
 Sulfur-fertilized units ..... 96  
 Sulfur-plus-nitrogen-fertilized units ..... 113
2. Average grazing capacity of the green-season units in days/acre:  
 Unfertilized units ..... 22.8  
 Sulfur-fertilized units ..... 41.4  
 Sulfur-plus-nitrogen-fertilized units ..... 55.5
3. Cost of the fertilizer program per acre/year including 6% interest charge discounted yearly:  
 Sulfur-fertilized units .... \$1.16  
 Sulfur-plus-nitrogen-fertilized units ..... \$4.72

The cost of the animals has been left out since the study was limited to the grazing problem. An additional set of costs, which we will call "range costs", are missing: investments in rangeland, equipment, upkeep, and improvements, plus labor, taxes, and interest on these investments. The study and the analysis of the data were not de-

signed to evaluate such costs, but our analysis did show that they may determine the kind of fertilizer program to be followed.

According to our data, if range costs were \$5.86/acre/year, the cost of grazing per animal would be about equal (\$21.54) for either a 96-day season on the sulfur-fertilized units or a 113-day season on the sulfur-plus-nitrogen-fertilized units. At the same time, the costs on the unfertilized units would be much higher (\$29.94). Range costs lower than \$5.86 would tip the scales in favor of sulfur-fertilized range. Higher range costs would favor sulfur-plus-nitrogen.

Several factors account for the lower cost of grazing per animal with a particular kind of fertilizer at a given evaluation of range costs. Probably the greatest contributing factor is the increased grazing capacity on the fertilized range units. A second factor is earlier range readiness on range units fertilized with sulfur-plus-nitrogen. As the cost of maintaining the livestock during the wintering period goes up, early range readiness becomes increasingly more valuable. Finally, as the costs of a resource such as rangeland and of labor increase, the relative cost of a fertilizer decreases. Thus when land and labor are high enough, the cost per animal will be least on the nitrogen-plus-sulfur-fertilized units. At one extreme it could be more economical to buy or lease more land than to fertilize. At the other extreme, great expense for fertilizer may be justified to get the highest possible production per unit of resource.

### Summary

In a grazing study at the San Joaquin Experimental Range, 60 lb of sulfur, 60 lb of sulfur plus 80 lb of nitrogen, or 0 lb of fertilizer were applied on annual-plant range. Both herbage production and cattle live-weight gain increased as a result. The

study, begun in mid-1959, included two years of severe drought and poor rainfall distribution.

The greatest effect of using fertilizer was to increase grazing capacity. Little important difference in daily gain was noted except in the first year of dry-season grazing. The number of animal-days of grazing in the dry season was increased by 45% on the sulfur-fertilized units, and by 141% on sulfur-plus-nitrogen-fertilized range units. On the same kind of range grazed in the green season, the increase was 82% on sulfur-fertilized units and 145% on sulfur-plus-nitrogen-fertilized units. Also the green season began an average of 17 days earlier on the sulfur-plus-nitrogen-fertilized range.

We considered the additional grazing capacity produced on

fertilized range a useful way of evaluating a fertilizer program. Even considering the longer green season and greater grazing capacity, the cost of grazing per animal for the sulfur-plus-nitrogen-fertilized range was higher than for sulfur alone so long as the cost of the rangeland, equipment, labor, etc. was below \$5.86 /acre/year. This includes consideration of the cost of maintaining the animal on winter range plus supplement during the 17 days when the green season had started on the sulfur-plus-nitrogen-fertilized units.

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