Chemical Curing of Range Grasses with Paraquat[1]

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Highlight

Low concentrations of paraquat, when applied to range grasses at anthesis, effectively arrested the redistribution of nutrients in the herbage portions during curing. Treated herbage, high in estimated feed value and saved "on the stump" for later use by grazing animals may be another useful tool for the western livestock producer. The results warrant continued investigations with paraquat and other chemicals which may have similar characteristics when applied to grass herbage.

The major source of roughage for the western cattle industry during late summer, fall, and in some areas, winter, comes from naturally-cured forage. This forage is often of low quality. Only partial success in replacing, supplementing, fertilizing, or managing this problem resource has been achieved in the past years.

Raleigh and Wallace (1965) summarizing six years of grazing studies on the Squaw Butte range, reported that range forage: (1) decreased in percent crude protein from 19 on May 1 to 3% on September 18 while crude protein digestibility decreased from 65 on May 20 to 26% on September 4; (2) increased in cellulose from 24 on May 1 to 30% on September 18, while cellulose digestibility decreased from 70 to 52% between May 29 and September 4; and (3) decreased in digestibility of gross energy and dry matter from 63 to 47% from May 29 to September 4. Nutritive and digestibility patterns of range grasses at Squaw Butte are similar to those in other grasses throughout the western region: Williams, 1953; Watkins, 1955; Marsh et al., 1959; Heinrichs and Carson, 1956; and Cook and Harris, 1950.

Concern about the low quality of range forage has stimulated research on methods to improve this forage. The two-crop system of grazing as described by Hyder and Sneva (1963) developed out of earlier investigations. Other studies concerned with the effect of growing point removal upon the subsequent distribution of nutrients in the plant directed our attention to less conventional means of growing point removal or the suppression of its dominance. Chemicals that would affect the growth of the growing point were sought and in 1961 paraquat (1,1′-dimethyl-4,4′-bipyridinium di(methylsulphate)) was one such chemical tested. Though not accomplishing the effect desired, a curing effect of the grasses occurred from the application of this chemical. This aspect warranted further investigation.

This paper presents the results of various studies conducted since 1961 which investigated the chemical paraquat as an agent to arrest the movement of nutrients within or from the grass plant. The studies considered (1) compositional changes in the herbage, (2) residual effect on herbage yield, (3) chemical residue remaining, and (4) paraquat rate and carrier volume. Results of in vivo and in vitro digestion trials of herbage from these and companion trials are reported elsewhere (Wallace et al., 1966).

Methods and Materials

All studies, except for one on a meadow site, were conducted on either native or seeded grass stands within the Squaw Butte summer range unit, 42 mi west of Burns in southeastern Oregon. This summer range unit, approximately 4,500 ft above sea level, receives about 11 inches of precipitation annually. Vegetation and soils on the Station have been described in detail by Eckert (1957).

Either split-plot or randomized block designs were used for experiments of 2 to 4 replications for separate studies on downy bromegrass-Brte-(*Bromus tectorum* L.), cereal rye (*Secale cereale* L.), crested wheatgrass-Agde-(*Agropyron desertorum* (Fish. ex Link Schult.), Siberian wheatgrass-Agsi-(*Agropyron sibiricum* (Willd.) Beauv.), Whitmar wheatgrass-Agin-(*Agropyron inerme* (Scribn. and Smith) Rydb.), tall wheatgrass-Agel-(*Agropyron elongatum* (Host) Beauv.), and Sherman bluegrass-Poam-(*Poa ampla* Merr.). The meadow trial was not replicated, but consisted of two 0.5-acre plots. The vegetation on the meadow site consisted primarily of rush and sedge (*Juncus* and *Carex* spp.).

Paraquat is a new chemical; its characteristics and uses in agriculture have recently been described by Springett (1963). The chemical may translocate, but most action is at the point of contact. Though light sensitive, the chemical is absorbed in darkness by the plant but phytocidal action occurs during active phosynthesis. Paraquat is completely soluble in water, is nonvolatile and when in contact with the soil is inactivated by the base exchange; thus, at low rates soil residual activity is nil.

Studies in 1962 and 1963 were primarily concerned with the retention of nutrients within the grass after treatment with paraquat. Even

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so, several levels of paraquat were employed, their inclusion was to provide preliminary information for the more detailed rate studies in subsequent years. Therefore, only portions of the 1962 and 1963 data are presented to eliminate duplication.

Study plots varied in size and thus required spray equipment compatable with the treatment area. A rechargeable, hand-held, aerosol type spray canister was used on small cheatgrass plots (5 ft^2) in 1962 while boom-type equipment was used in other studies with treatment areas larger than 100 ft^2. Spray solution was applied at 20 to 30 psi pressure at 2 to 3 mph with the boom held approximately 4 ft above the ground surface to insure full coverage at the seedhead level. Water was used as the carrier in all years and in most studies at 10 to 15 gal/A: exceptions being, (1) downy bromegrass study (40 gal/A), (2) meadow study (40 gal/A), and (3) carrier volume and paraquat rate studies (5, 10, 15, 20, and 30 gal/A). A cationic surfactant, X-77, was added at the rate of 0.5% total solution to all spray solutions in all years. Treatment applications were confined to late afternoon or evening hours when the air was calm except in 1963 when applications in the evening hours were compared with applications in the morning hours.

Green weights of herbage yield samples were taken, followed by oven drying in a forced air electric oven at 160 F and all yields were expressed on an oven-dry basis. Samples for chemical analysis were similarily dried, ground through a 20-mesh screen in a Wiley mill, and then stored in air-tight glass jars.

Chemical analysis of the herbage included nitrogen, phosphorus, potassium, calcium, and carotene. Methods as prescribed by the A.O.A.C. (1955) were used; nitrogen being determined by the Kjeldahl method with crude protein calculated as (N x 6.25). Chemical residue in treated and untreated herbage was determined by the Diablo Laboratories, Berkeley Research Center, Berkeley, Calif.

Typical low precipitation (Table 1) was received during the summer months of 1962, 1963, and 1966; however, unusually large amounts were

Table 1. Precipitation in inches for selected months and cropyear at Squaw Butte Experiment Station.

Year	June	July	August	Crop-year
1962	0.75	0.00	0.07	8.14
1963	1.59	0.23	0.21	13.50
1964	2.45	1.38	1.18	10.30
1965	2.54	0.90	2.04	12.47
1966	1.56	0.13	0.35	7.73
20-year Mean	1.30	0.26	0.47	11.02

[1] September 1 to June 30, inclusive.

received in the summers 1964 and 1965. Thus, the results reflect both the normal, dry summer response as well as the response in the unusually wet summers.

Results and Discussion

Dry Summers.—Crude protein declined 48% in 1962 and 58% in 1963 in a native range grass, bluebunch wheatgrass *(Agropyron spicatum* (Pursh) Scrib. and Smith), curing naturally over a 4-month period beginning in late June (Table 2). Crude protein of paraquat-treated herbage of that grass declined less than 10% during the same period. Similar treatment effects were measured in two other native grasses, Idaho fescue *(Festuca idahoensis* Elmer) and Junegrass *(Koeleria cristata* (L) Pers.) Following approximately 100 days of curing in 1963 ending October 28, crude protein of crested wheatgrass on control plots declined 28% but that cured with paraquat declined less than 2% (Table 2). The smaller difference in crested wheatgrass in 1963 was due to a later application date which resulted in lower initial levels of herbage crude protein.

Data in Table 2 are partial or meaned data; thus, the attachment of significant levels is not valid. However, in all three studies the interaction of harvest date with paraquat treatment was significant while main effects of treatment and harvest date were significant only in the native range studies.

The arresting action of paraquat on P, K, and Ca content of crested wheatgrass (Table 2) indicates that the retention of these minerals was affected until removed by undetermined causes; but, perhaps by leaching of fall rains. Main effects of paraquat treatment and harvest date and their interaction were significant sources of variation in the analysis of each mineral. Thus, in late fall of dry summers the level of P and K of crested wheatgrass cured with paraquat was not different while Ca level was lower than that cured naturally.

No significant difference in herbage yield due to treatments was measured (Table 2). Since treatment application in most years was timed to coincide with peak yield (which also is approximated by anthesis in these grasses) no reduction in yield should be anticipated except for loss due to treatment effect.

Wet Summers.—Data for years in which summer precipitation was unusually high are presented in Table 3. In both years regrowth of grasses on plots treated with paraquat was stimulated and the data therefore confounded with regrowth herbage. The precipitation also influenced grasses on control plots but here apical dominance was still active and little or no new shoot growth was initiated. The main effect of precipitation on control plots was an extension of the green herbage season. A shortened harvest season in 1964 occurred because cattle broke into the experimental area and consumed all the herbage from paraquat treated plots to be sampled in August.

In 1964, crude protein content of crested wheatgrass was reduced approximately 50% in a 40-day period beginning June 10 (Table 3). In the same period, crude protein in herbage from plots treated with paraquat increased 10%. Regrowth herbage

Table 2. Crude protein, herbage yield, and mineral concentrations in range grasses cured either artificially or naturally in dry summers.

Species and treatment date	Sampling date	Crude protein % N.C.[1]	Crude protein % C.C.[1]	Herbage yield lb/A. N.C.	Herbage yield lb/A. C.C.	Phosphorus % N.C.	Phosphorus % C.C.	Calcium % N.C.	Calcium % C.C.	Potassium % N.C.	Potassium % C.C.
6/22/62											
Bluebunch	6/22	9.4	9.3	332	322						
wheatgrass	7/17	7.4	9.7	310	348						
	8/20	5.8	9.8	273	238						
	10/23	4.9	9.2	198	235						
6/23/63											
Bluebunch	6/23	10.0	10.4	624	626						
wheatgrass	7/26	6.6	9.2	675	518						
	8/26	5.9	8.8	536	520						
	10/30	4.0	9.4	453	615						
	2/26/64	4.1	11.4	......	......						
7/15/63											
Crested	7/18	5.3	6.5	750	675	0.110	0.125	0.188	0.198	0.776	0.835
wheatgrass	7/25	5.8	5.6	757	737	0.127	0.119	0.170	0.174	0.840	0.756
	8/25	5.0	5.4	822	562	0.108	0.134	0.236	0.189	0.706	0.781
	9/28	5.6	5.1	722	770	0.100	0.124	0.199	0.155	0.644	0.875
	10/28	3.8	6.4	700	622	0.061	0.068	0.253	0.145	0.240	0.224

[1] N.C. = naturally cured.
C.C. = chemically cured at 0.84 lb/A paraquat cation in 1962; but, those in 1963 at 0.80 lb/A the surfactant X-77 was added at 0.5% of the total volume.

was present in samples from paraquat treated plots and accounts for the increased crude protein content. Over a 10-week period beginning June 17, 1965 the mean crude protein content of five introduced range grasses declined 34% while crude protein content of paraquat-treated herbage of those five grasses (not including regrowth) declined 14%. When regrowth from the treated plots was included the mean crude protein content showed an increase of 14%.

Table 3. Crude protein and mineral concentrations (in percent) in grasses cured either artificially or naturally in wet summers.

Species and treatment date	Sampling date	Crude protein N.C.[1]	Crude protein C.C.[1]	Phosphorus N.C.	Phosphorus C.C.	Calcium N.C.	Calcium C.C.	Potassium N.C.	Potassium C.C.
6/10/64									
Crested	6/10	10.2	10.1	0.241	0.250	0.149	0.138	0.908	0.972
wheatgrass	6/16	8.8	9.4	0.238	0.234	0.145	0.131	0.958	0.876
	7/22	5.4	11.0	0.164	0.250	0.205	0.138	0.715	0.907
6/18/65									
Introduced	6/17	7.9	7.9	0.192	0.198	0.207	0.207	1.055	1.026
grasses[2]	7/16	6.0	8.1	0.169	0.188	0.201	0.172	0.899	0.901
	8/31	5.2	9.0	0.137	0.147	0.226	0.164	0.518	0.689

[1] N.C. = naturally cured
C.C. = chemically cured with 0.8 lb/A of paraquat cation + X-77
[2] Includes Agde, Agsi, Agel, Agin, and Poam. Values are means of individual determinations of each specie.

Concentrations of P, K, and Ca in grasses cured naturally in the wet summers followed patterns established in dry summers (Table 3). In 1964, major rains occurred after the last harvest date; thus, no decline in mineral content of paraquat treated herbage was obtained. Summer rains in 1965 began early in July and continued through August and were associated with a continued decline of P, K, and Ca in paraquat-treated herbage. Estimates of mineral concentrations of paraquat-treated herbage hand separated from subsamples on August 31, 1965 were 0.095, 0.096, and 0.216% for P, Ca, and K, respectively. Those amounts were considerably lower than amounts determined from herbage on control plots on the same date. However, when grass regrowth subsequent to paraquat treatment was considered with the cured herbage portion the mineral concentrations were increased such that concentrations of P and K were higher than that of control plots on the last harvest date. The results show greater losses of the minerals in treated herbage in wet than in dry summers but contributions from new regrowth in the wet summers can compensate for this loss.

Herbage yield in the wet summers from plots treated with paraquat were significantly re-

Table 4. Herbage yield in a wet summer as influenced by artificial curing[1].

Treatment date	Harvest date June 10	June 30	Aug. 20
		lb/A	
Control	868	1,400	1,416
June 10	——	852	816
June 30	——	——	822

[1] Paraquat applied at 0.8 lb/A of the cation.

Table 5. Herbage crude protein concentrations (in percent) in 1964 as influenced by rates of paraquat applied June 22 of that year.

Date	Herbicide acid rate (lb/A) + X-77 0.0	0.2	0.4	0.6	0.8	Mean
June 22	9.6	9.4	9.2	10.1	9.2	9.5[a]
June 27	6.0	8.8	9.4	9.8	9.7	8.8[b]
Mean	7.8[c][1]	9.1[b]	9.3[b]	9.9[a]	9.4[b]	

[1] Means with unlike superscripts significantly (0.05) differ from each other.

duced. An example of this yield loss is shown in Table 4. In addition, subsamples of the yield samples on August 20 were hand separated for an estimate of new growth and paraquat-cured herbage. Paraquat-cured herbage was 57 and 92% of the total yield on August 20 from plots treated on June 10 and June 30, respectively. When related back to the herbage yield present at the time of treatment it was determined that approximately 45% of the original herbage treated was lost. Since this loss of herbage was not seen as litter it is suggested that the loss occurred through a decomposition process.

Paraquat Rate and Carrier Volume.—Rates of 0.0, 0.2, 0.4, 0.6, and 0.8 lb/A of the cation in 10 gal of water were applied to crested wheatgrass in the evening hours of June 22 and the morning hours of June 23, 1964. Percent crude protein in the herbage sampled on June 21 and July 27 were obtained and the means are presented in Table 5. Main effects of paraquat rate and harvest date and their interaction were highly significant. No significant difference was obtained in percent crude protein due to time of application.

Paraquat rates of 0.0, 0.1, 0.2, and 0.3 lb/A of the cation were applied in factorial combination with 5, 10, 15, and 20 gal of water in 1965 and with 5, 10, 15, and 30 gal of water in 1966. Main effects of harvest date and paraquat rate and their interaction were again highly significant sources of variation in the analysis of herbage percent crude protein in both years. The interaction for 1965 is presented in Fig. 1 while that of 1966 is in Table 6. A significant arrestment of plant crude protein was achieved with just 0.1 lb/A of paraquat; but, optimum effectiveness was not obtained. In 1965, all paraquat rates caused significant differences in the percent crude protein retained. In 1966, the 0.2 and 0.3 lb/A rates did not differ from each other but both caused significantly greater percent crude protein to be retained in the herbage than the 0.1 lb/A rate. It is therefore inferred that the 0.2 lb/A provides an acceptable level of curing in these grasses.

A significant carrier volume by harvest date interaction also occurred each year. In 1965, it occurred because crude protein content was lower in crested wheatgrass harvested on the last two sample dates from plots treated with 20 gal/A. In 1966, the interaction was not nearly so evident but is believed to have occurred because of a more rapid decline of the herbage crude protein on plots treated at 5 gal/A. Though the interaction can be explained for each year, the significance of the interaction is not recognized.

It is inferred from the nonsignificant carrier volume by paraquat rate interaction in each year that treatments were equally effective when applied at 5 to 30 gal/A total solution.

Paraquat Residue — Following treatment with 0.2, 0.5, and 0.8 lb/A of the cation, initial and subsequent amounts of paraquat in the herbage were determined in 1965 (Fig. 2). Levels of paraquat in crested wheatgrass (0.2 and 0.8 lb/A rates) decreased rapidly in the first 30-day period. This is in agreement with decreases reported in Great Britain (Warboys and Ledson, 1965). Decline in residual paraquat was less rapid in the second 30-day period; however, at the 0.2 lb/A rate 2 ppm or less paraquat were measured after 30 days of exposure.

Table 6. Percent crude protein in herbage as influenced by rates of paraquat applied on June 14, 1966.

Harvest date	Paraquat rate (lb/A) 0.0	0.1	0.2	0.3	Mean
June 14	7.8	8.0	7.8	7.9	8.1[a]
June 22	4.8	6.5	7.8	8.0	6.8[b]
Mean	6.3[a]	7.3[b]	7.8[c]	8.0[c]	

[1] Means with unlike superscripts differ significantly from each other at the .05 level.

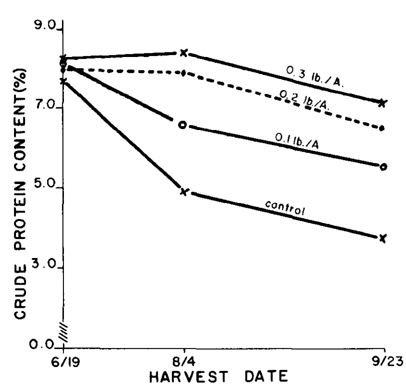

Fig. 1. Crude protein content in crested wheatgrass as influenced by paraquat treatments on 6-19-65.

When applied to meadow vegetation the breakdown of paraquat was less rapid than in crested wheatgrass. After 90 days of exposure, meadow vegetation treated with 0.5 lb/A of the cation still contained about 10 ppm paraquat. It is suggested that this denser meadow vegetation reduced light intensity within the stand which slowed paraquat decomposition.

Residual Influence on Herbage Yield. — The influence of paraquat treatment upon yield in subsequent years was measured in 1963 and 1964. On June 18, 1963 two replications of the native range study initially treated in 1962 were retreated with 0.8 lb/A of the cation. The other two replications had been sampled on June 13, 1963 for a measure of first year residual influence. Herbage yield on June 13, 1963 from plots treated in 1962 was 200 lb/A less than yield from control plots. This difference approached significant at the 5% level. Herbage yield sampled later in that year from plots retreated in 1963 did not differ from the yield of control plots. Likewise, herbage yield sampled in June, 1964 from plots treated in both 1962 and 1963 did not differ from that of control plots. In addition, paraquat treatment of crested wheatgrass in 1963 did not reduce herbage yield on those plots one year later.

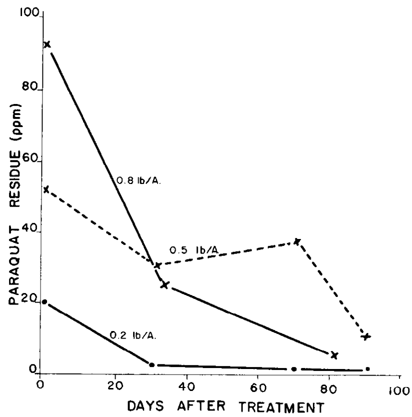

Fig. 2. Paraquat residue remaining in plant herbage (0.2 and 0.8 lb/A rate applied to crested wheatgrass; 0.5 lb/A rate applied to meadow species).

Herbage Dry Matter Content. —Dry matter content of grasses treated with paraquat increased significantly following treatment. Three days following treatment on July 15, 1963 dry matter content of crested wheatgrass was 64% while that of untreated herbage was 54%. Approximately 70 days later the dry matter contents had increased to 90 and 68%, in the same order.

Herbage Carotene Content.—Carotene content in the treated herbage was immediately reduced; thus, a distinct green color loss within a few days after treatment with paraquat is characteristic. In 1963, the carotene content of crested wheatgrass sampled three days after treatment with paraquat on July 15 was 5.5 ppm as compared with 13 ppm in untreated wheatgrass. The concentrations 100 days later were 8 and 10 ppm in herbage chemically cured and naturally cured, respectively.

Paraquat Effect on Other Species.—In addition to the grasses previously discussed, paraquat was tested in replicated trials on downy bromegrass and common rye; and in a non-replicated trial on native meadow species (Table 7). The retention of crude protein in herbage treated with paraquat was similar in pattern and magnitude to that previously presented.

Differential Species Response to Paraquat.—Regrowth of five species in 1965 to treatment with paraquat on June 18 was also observed and measured. The percent of green growth on August 20 in the total sample was 18, 24, 37, 38, and 80 respectively for Agel, Agde, Agsi, Agin, and Poam. In Agel, Agde, and Agsi this green growth was primarily second-crop stems while in Agin and Poam both second-crop stems and first-crop stems were present. With 100% spray coverage, regrowth of perennial grass species after treatment with paraquat should not differ greatly from that resulting from a clipping treatment, as topkill is all that is being affected. Thus, species response following treatment with paraquat would be a function of the physio- and phenological characteristics of the grass, time, and effectiveness of application and environmental conditions existing for growth after treatment. Because of this difference in response by perennial species and the susceptibility of annuals to this chemical it has been found to be an effective means in renovating pastures in England (Douglas, Lewis, and McIllvenny, 1965).

Table 7. Crude protein retention in downy bromegrass, cereal rye, and meadow grass species as influenced by artificial curing.

Year, species and treatment	Treatment date	Harvest date and protein % 1	2	3
1962				
Brte	5/31	5/31	6/11	7/5
Control		9.3	8.9	6.1
0.42		9.7	10.0	9.3
1965				
Cereal rye	6/18	6/17	7/1	7/16
Control		11.2	8.1	7.4
0.80		10.5	11.5	9.7
Meadow[2]	7/15	7/16	8/16	10/16
Control		8.7	5.9	4.6
0.50		8.6	8.2	6.9

[1] Pounds per acre of paraquat cation + X-77

[2] Juncus and Carex spp., primarily.

Summary and Conclusions

Paraquat was used to cure range grasses in the years 1962 to 1966 in southeastern Oregon. When applied at anthesis to native and introduced grasses, paraquat effectively altered redistribution of N, P, K, and Ca in the herbage. The decline of these elements following treatment in dry summers was minimal until fall rains; then, losses of P, K, and Ca were greater than N. In wet summers, decline of N, P, K, and Ca in treated herbage occurred throughout the summer and was greater than in a dry summer; however, summer rains also caused new growth on treated plots. Following either wet or dry summers, herbage in the fall on treated plots was higher in estimated feed value than herbage on plots cured naturally.

Either evening or morning applications of 0.2 lb/A of paraquat cation in 5 to 30 gal of water plus a cationic surfactant provided an acceptable level of curing in these grasses.

Herbage yield from plots treated in a wet summer was reduced 45% but in dry summers no yield reduction on treated plots was measured. Herbage yield following 1 or 2 consecutive treatment years was not reduced.

Loss of herbage green color and increasing dry matter content with paraquat treatment was a typical response of all grasses. A large loss of carotene in crested wheatgrass herbage was measured in one year, 3 days after treatment. In a wet summer, regrowth of grasses treated with paraquat varied and was related to spray penetration, physiological and phenological characteristics of the grasses. Two ppm or less of paraquat residue was measured in crested wheatgrass 30 days after treatment with 0.2 lb/A. In a more dense meadow vegetation treated with 0.5 lb/A paraquat, residue concentrations of 10 ppm were measured 90 days after treatment.

Paraquat Clearance

Paraquat was used experimentally in these studies. At the time of writing, paraquat was not cleared (registered) for use in curing herbage for forage. Until paraquat is registered for this use, it should not be employed.

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