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Shoot Production and Mineral Nutrient Assimilation in Cheatgrass Communities

Abstract

Shoot production at peak yields in cheatgrass communities on the U.S. Department of Energy's Hanford Site in southeastern Washington during the 1968-69 growing season averaged 212 and 370 g per m² dry wt. in communities located at 520 m (high) and 323 m (low) elevations respectively. Litter (dead plants) at the high elevation averaged 362 g per m² as compared to 225 g at the low elevation. More precipitation and more soil water were present at the high elevation. Shoots and litter from the high elevation had lesser concentrations of assimilated nitrogen suggesting that the availability of nitrogen from the root zone was a factor constraining shoot production at the high elevation.

Introduction

Cheatgrass (*Bromus tectorum* L.) is an annual grass of Eurasian origin that has formed self-sustaining communities on man-disturbed lands throughout the semi-arid, relatively cold wet winter, and hot dry summer, climate of eastern Washington (Daubenmire 1970, Mack 1981). Although cheatgrass has been studied from an autecological point of view (Hulburt 1955, Harris 1967, Hinds 1975) and as an undesirable rangeland grass (Young *et al.* 1979); it has received relatively little study as a functional, self-sustaining plant community (Cline and Rickard 1973, Uresk *et al.* 1979, Rickard and Sauer 1982).

The purpose of this study was to determine annual shoot production in two 30-year old cheatgrass communities at different elevations and to compare their concentrations of shoot assimilated mineral nutrients.

Study Area

The study area is the Arid Lands Ecology (ALE) site a 300 km² ecological research study area located on the U.S. Department of Energy's Hanford Site in eastern Washington. Dryland wheat was raised at several places on the ALE Site prior to government acquisition but farming ceased in 1943 when the land was acquired for government use. After abandonment the fields were promptly invaded by cheatgrass. After 30 years there has been only a token invasion of the fields by the native perennial taxa although the fields are surrounded by vast acreages of native sagebrush-bunchgrass communities (*Artemisia tridentata-Agropyron spicatum*) (Rickard and Sauer 1982). The land of the ALE Site had a history of livestock grazing prior to 1943, but since that time livestock grazing has been essentially excluded, with only fugitive grazing until 1968 when all livestock grazing was excluded.

Methods

Communities at elevations of 520 and 323 meters above mean sea level were chosen for this study. Single study plots each 20x50 m (0.1 ha) in size were located near the center of each field. Samples of surface soil from five locations within each of the study plots were taken to a depth of one decimeter using a soil auger. Soil samples were air dried, screened through a 2 mm mesh screen to remove roots and other organic debris, and thoroughly mixed before being submitted to chemical analyses. The soil type at both sites is Ritzville silt loam (Daubenmire 1970).

Six to ten one square foot (0.093 m^2) quadrats were sampled for shoot biomass at each field. These quadrats were randomly located within each study plot at harvest dates distributed from the beginning to the end of the spring growth period March to May in 1969. Live shoots were severed at ground level and hand-segregated into two general botanical categories; cheatgrass and forbs. On the date of peak harvest in May, the ripe spikes of cheatgrass (culms with attached caryopses), were cut from the attendant foliage (straw) so that mineral analyses could be conducted on the separate tissues. Dead standing and prostrate plant materials (litter) were cleared from those quadrats harvested at the beginning and at the end of the spring growing season. All plant materials were oven dried at 50-55°C and weighed. The results are expressed as grams dry weight per m^2. Dried shoots and litter were milled to pass a 2 mm screen and aliquots taken for chemical analyses of nitrogen, phosphorous, potassium, and calcium.

The nitrogen concentrations of plant and soil samples were determined by the Kjeldahl method, P was determined by colorimetry, and Ca and K by atomic absorption spectrometry (A.O.A.C. 1965).

Precipitation was measured at each field using standard U.S. Weather Bureau rain gauges. Soil water was determined by taking duplicate soil cores at one decimeter depth increments to one meter deep by sampling periodically from the beginning to the end of the spring plant growth season. Water content of soil samples was determined gravimetrically after oven-drying at 105°C. Plant available soil water was judged to be the soil water content in excess of 6 percent on a dry weight basis.

Results and Discussion

On the average, soil organic matter, nitrogen, phosphorus, potassium, calcium, pH, and total bases were greater on the low elevation field than on the high elevation field (Table 1). The growing season precipitation (October 1968-May 1969) was 3.4 cm greater on the high elevation field, 25.1 cm as compared to 21.7 cm. At the end of the spring growing season the available soil water had been mostly extracted from the soil profile by the evapotranspiration process at the low elevation field (Figure 1). A small amount of available soil water remained in the soil profile at the high elevation community at the end of the spring growing season indicating that cheatgrass was not so efficient at extracting the soil water that had penetrated deeper than 0.5 meters.

At the high elevation community, cheatgrass dominated shoot biomass from beginning to end of the spring growing season. Lance-leaf microseris (*Microseris lanciniata*), a perennial, and yellow salsify (*Tragopogon dubius*), a biennial, were

TABLE 1. Soil properties, means and ranges of values, (n = 5), obtained for samples of the surface dm of soil from high and low elevation cheatgrass communities in southeastern Washington.

Soil Properties	High Elevation	Low Elevation
Organic Matter %	1.6 (1.5-1.8)	2.0 (1.6-3.5)
Nitrogen %	.073 (.064-.086)	.094 (.072-.112)
Phosphorus μg/g	34 (32-38)	32 (24-46)
Potassium μg/g	1100 (940-1210)	1400 (1080-1630)
Calcium μg/g	2600 (2500-2900)	3200 (2900-3700)
Soil pH	(6.4-6.9)	(7.0-7.3)
Bases meq/100g	10.6 (10-11.4)	12.5 (11.6-13.6)

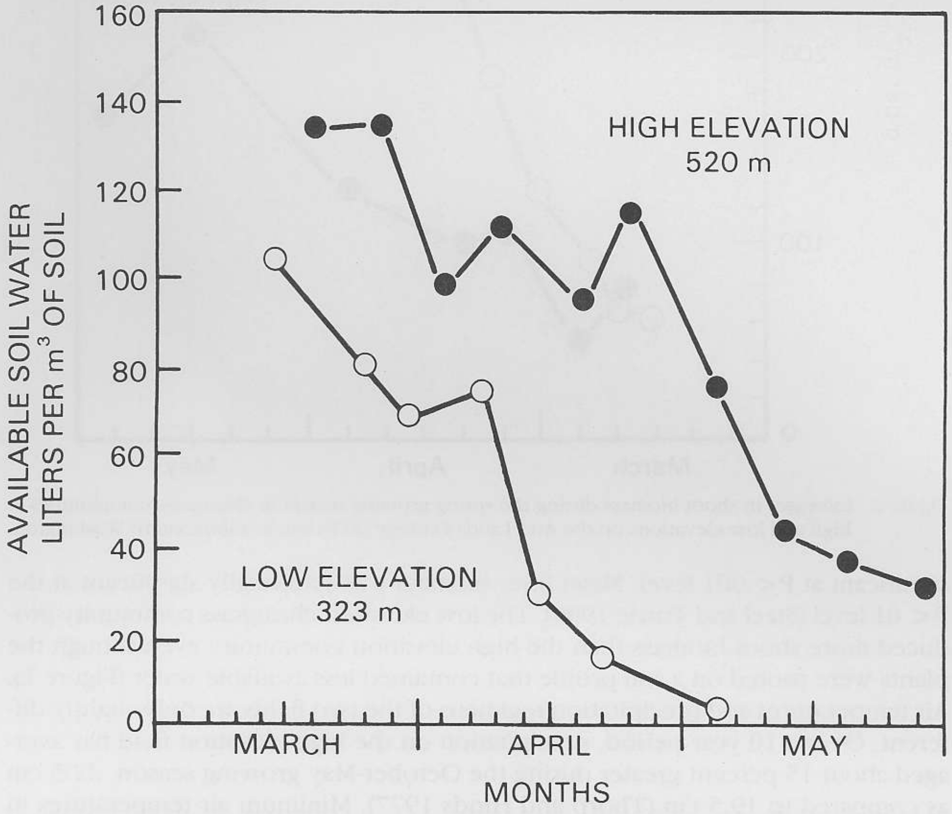

Figure 1. Decline of available soil water in the upper meter of soil during the spring growing season at high and low elevation cheatgrass communities on the Arid Lands Ecology (ALE) Site in southeastern Washington.

the most abundant forbs in this community. The low elevation community supported about equal amounts of cheatgrass and an annual forb, tumble mustard (*Sisymbrium altissimum*). Microseris and yellow salsify did not grow at the low elevation. Shoot biomass attained its peak in late May at 212g per m² dry weight on the high elevation field and at 370 g/m² in early May on the low elevation field (Figure 2). At peak shoot production litter weights average 362 and 225g per m² on the high and low elevation fields, respectively. Using t-test statistics, the difference between mean shoot biomass at peak yield at the two elevations was

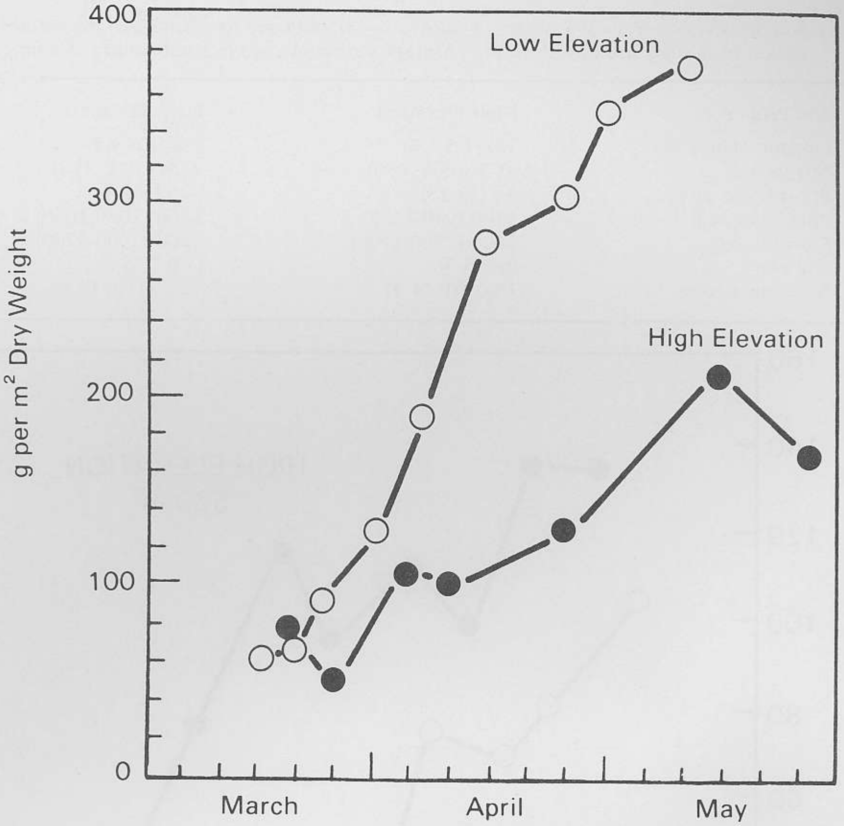

Figure 2. Increases in shoot biomass during the spring growing season in cheatgrass communities at high and low elevations on the Arid Lands Ecology (ALE) Site in southeastern Washington.

significant at $P < .001$ level. Mean litter biomass was statistically significant at the $P < .01$ level (Steel and Torrie 1980). The low elevation cheatgrass community produced more shoot biomass than the high elevation community even though the plants were rooted on a soil profile that contained less available water (Figure 1). Air temperatures and precipitation regimens of the two fields are only slightly different. Over a 10 year period, precipitation on the high elevation field has averaged about 15 percent greater during the October-May growing season, 22.5 cm as compared to 19.5 cm (Thorp and Hinds 1977). Minimum air temperatures in January at the high elevation averaged − 17.5 and − 15.5°C at the high and low elevations, respectively. The close similarities in microclimate at the two sites suggests that edaphic factors rather than atmospheric factors are the constraints to shoot production at the high elevation field. The role of microclimate and soil as a determinant of cheatgrass growth and nitrogen assimilation are intimately related and cannot be separated in most kinds of field investigations (Hinds 1975).

As the growing season progressed concentrations of N, P, K, and Ca in cheatgrass shoots declined. Nitrogen, P, and K concentrations also tended to decline in forb shoots but Ca concentrations tended to increase (Figure 3). In both communities, forb shoots had higher concentrations of N, P, K, and Ca than did cheatgrass shoots (Figure 3).

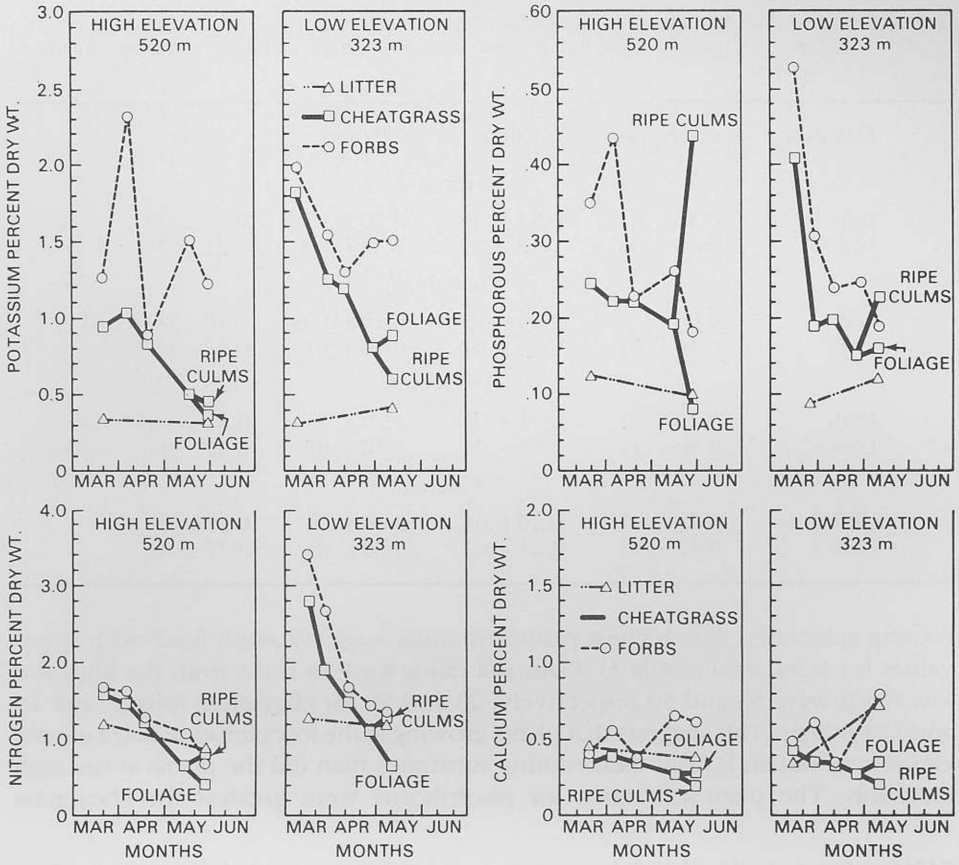

Figure 3. Nitrogen, phosphorus, potassium, and calcium concentrations in shoots of cheatgrass and forbs and litter from high and low elevation cheatgrass communities on the ALE Site in southeastern Washington during the spring growing season.

The ripened culms of cheatgrass had greater concentrations of N and P than their attendant foliage but foliage had greater concentrations of Ca (Table 2). Potassium had its greatest concentrations in foliage rather than ripened culms at the low elevation but at the high elevation the ripened culms had the greater concentrations of K.

The litter had lower concentrations of K and P and higher concentrations of N and Ca than did the mature shoots. This suggests that P and K are not so strongly retained in the dead plants (litter) and that N and Ca are more strongly retained in the litter. Calcium concentrations of litter probably show elevated levels of Ca because the calcium bound in dead plants is not as readily mobilized by leaching and by the decay processes as P and K. The elevated concentrations of N in litter could be due to assimilation of nitrogen by microorganisms utilizing the organic carbon in the litter as an energy source. Also there may be some differential inputs of N to the litter from wet and dry depositions from the atmosphere at the two locations.

The plant soil ratio (concentration in dry plant tissue/concentration in dry soil) is one way to express the ability of plants to obtain mineral nutrients from their

TABLE 2. Mean concentrations (percentages of dry weight ± SE) of N, P, K, and Ca in cheatgrass foliage, ripe culms, forb shoots, and litter from high and low elevation cheatgrass communities.

Elevation	Cheatgrass	Culms	Forbs	Litter
		Nitrogen		
High	0.38 ± .01	0.82 ± .08	0.70 ± .03	0.78 ± .09
Low	0.65 ± .08	1.38 ± .09	1.36 ± .08	1.22 ± .05
		Phosphorus		
High	0.08	0.44 ± .02	0.18 ± .009	0.10 ± .004
Low	0.16 ± .03	0.23 ± .01	0.19 ± .01	0.12 ± .03
		Potassium		
High	0.35 ± .01	0.44 ± .02	1.20 ± .13	0.32 ± .005
Low	0.88 ± .14	0.57 ± .03	1.50 ± .09	0.42 ± .04
		Calcium		
High	0.29 ± .01	0.20 ± .01	0.66 ± .04	0.39 ± .01
Low	0.37 ± .05	0.21 ± .01	0.80 ± .03	.077 ± .02

rooting substrates. The highest plant/soil ratios were obtained for P with lesser values for N>K>Ca (Table 3). Plant/soil ratios for P in forbs from the high and low fields were 53 and 59 respectively, 23 and 50 for cheatgrass foliage, and 29 and 37 for litter. This suggests that plants growing at the low elevation had a greater capacity to obtain P from their rooting substrates than did the plants at the high elevation. The plant/soil ratios for phosphorus were greatest for cheatgrass

TABLE 3. Plant/soil ratios for N, P, K, and Ca in cheatgrass foliage, ripe culms, forb shoots and litter from high and low elevation cheatgrass communities.

Elevation	Cheatgrass	Culms	Forbs	Litter
		Nitrogen		
High	5.2	11	9.6	11
Low	6.9	15	14	13
		Phosphorus		
High	23	129	53	29
Low	50	72	59	37
		Potassium		
High	3.2	4.0	11	2.9
Low	6.3	4.1	11	3.0
		Calcium		
High	1.1	0.77	2.5	1.5
Low	1.2	0.66	2.5	2.4

Plant/soil ratio = the concentration of mineral nutrient in dry soil divided by the concentration of the mineral nutrient in dry plant tissue.

ripened culms. This suggests that cheatgrass shoots have some ability to concentrate P in the ripened culms rather than foliage and that this concentration process was most pronounced at the high rather than the low elevation.

The plant/soil ratios for nitrogen in the three categories (cheatgrass foliage, cheatgrass ripened culms, and litter) ranged between 5.2 and 11 on the high field and between 6.9 and 15 on the low field. The ratios for potassium ranged between 2.9 and 11 in the high field and 3-11 on the low field (Table 3). The calcium ratios ranged between 0.77 and 2.5 on the high field and 0.66-2.5 on the low field. These ratios indicate that potassium and calcium were about equally available for shoot assimilation on both fields. Nevertheless, there was a small but consistent difference in plant/soil ratios for N with the low elevation field being more efficient for nitrogen assimilation as judged by the higher plant/soil ratio.

Once mineral nutrients are assimilated into living shoots of cheatgrass they can be reallocated within the plant. In the early stages of cheatgrass growth, mineral nutrients are allocated solely to vegetative tissues. As the growing season advances nutrients are reallocated from foliar tissues to the flowering culms and especially to the developing seeds. The nitrogen and phosphorus incorporated into seeds has the potential to be passed directly to the new generation of seedlings. Although the amount of nitrogen and phosphorus is very small in terms of a single seed, the amount is more impressive when the total seed production is considered as a community component (Figure 4). Approximately 30 percent of the shoot biomass of mature cheatgrass is allocated to ripened culms with 70 percent in the foliage. Not all of the N and P assimilated in seeds is passed on to the new generation of cheatgrass. Some of the seeds do not germinate and they contribute their mineral nutrient burdens to the litter. Also some of the seedlings die and become incorporated into the new litter component (Figure 4). In this way the litter serves as an accumulation site for nutrients as the new litter ages to become old litter, (i.e., more than one year old dead plants). Over a period of time, other nutrients bound in the old litter are transferred to the underlying mineral soil by the breakdown and decomposition of litter and by leaching. Once these nutrients enter the soil they may be available for prompt assimilation by the living plants (Jones and Woodmansee 1979, Woodmansee and Duncan 1980). Cheatgrass communities do not have a capability to store nutrients in long-lived tissues e.g. wood or grass crowns as do sagebrush-bunchgrass communities and other kinds of perennial grass and graminoid communities in western North America. To sustain a high level of shoot production from year to year cheatgrass communities depend upon a prompt return to the root zone of the pool of nutrients bound in dead plants. Coleman *et al.* (1983) have shown that relatively small pools of rapidly cycling components account for the major proportion of the N and P taken up by plants.

The dead tissues of annual grasses are expected to decay more quickly than the woody tissues but the rate of decomposition is not known. This suggests that radioactive isotopes of nitrogen could be used as tracers to determine the transfer rates of shoot nitrogen between the various components of cheatgrass communities as illustrated in Figure 4. The radioactive isotope ^{15}N has been used to elucidate the rate of nitrogen transfer in Alaskan forest communities (Van Cleve and White 1980) and the method seems applicable to cheatgrass communities.

The distribution of nitrogen and phosphorus among the major aboveground components of cheatgrass commmunities in Washington can be compared with

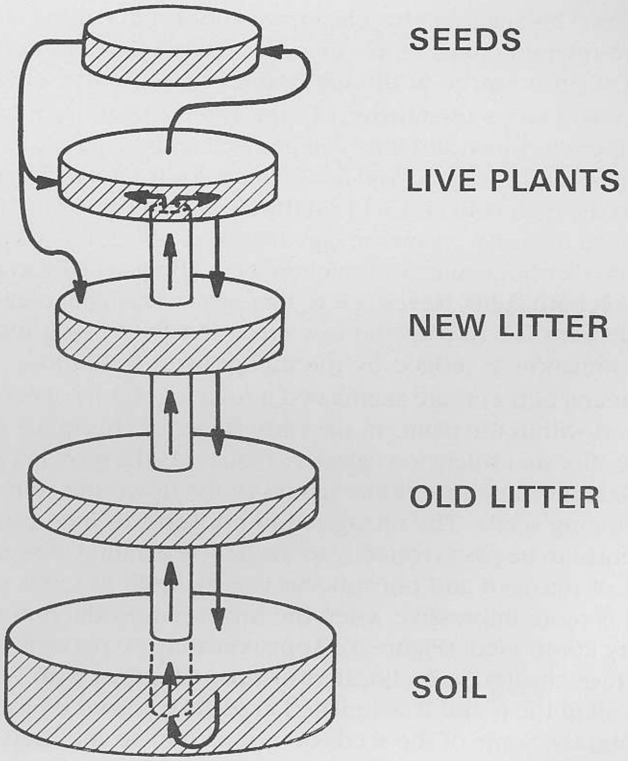

Figure 4. Schematic diagram showing the major community components of a cheatgrass community and the expected routes of mineral nutrient movement.

other kinds of low production wild plant communities in western North America (Chapin 1980, Woodmansee and Duncan 1980). Twenty-four percent of the total nitrogen in the aboveground biomass was in the litter component of a California annual grass community (Table 4). This compares with values of 20 and 67 percent for the cheatgrass communities in this study. The litter component of cheatgrass communities contained 24 and 53 percent of the aboveground P as compared to 19 and 27 percent in a California annual grass community. These data indicate that spatial and temporal heterogeneity is to be expected in annual grass communities and that several consecutive years of study are required to obtain representative values.

The aboveground biomass of cheatgrass communities contained 1.56-2.6 percent of the total community N and 8 percent of the P (Table 5). In contrast, Arctic wet meadow and tussock communities contained less than one percent of the community N and only 0.3-1.3 percent of the P. The relatively large percentage of aboveground P in the cheatgrass communities is attributed to the high allocation of P to the ripened culms of cheatgrass as compared to low P content foliar tissues.

A shortgrass prairie (*Bouteloua gracilis*) community in eastern Colorado had about the same amount of N in the total biomass as did the cheatgrass communities (Table 5) but the prairie community had a greater percentage of N allocated to aboveground biomass. This is a reflection of the large amount of living biomass

TABLE 4. Comparison of N and P in shoot biomass and litter (g per m^2) in annual grass communities in Washington and California. ( ) = percent of total biomass.

Category	Location			
	Washington High Elev.	Washington Low Elev.	California[1]	California[1]
		Nitrogen		
Grass	1.26 (30)	2.76 (43)	1.29 (16)	3.60 (63)
Forb	0.13 (3)	2.31 (37)	4.71 (60)	0.72 (13)
Total Shoot	1.39 (33)	5.07 (80)	6.00 (76)	4.32 (75)
Litter	2.82 (67)	1.30 (20)	1.92 (24)	1.40 (24)
Total	4.21	6.37	7.92	5.72
		Phosphorus		
Grass	0.29 (43)	0.46 (41)	0.36 (29)	0.25 (40)
Forb	0.03 (4)	0.39 (35)	0.65 (52)	0.20 (32)
Total Shoot	0.32 (47)	0.85 (76)	1.01 (81)	0.45 (72)
Litter	0.36 (53)	0.27 (24)	0.24 (19)	0.17 (28)
Total	0.68	1.12	1.25	0.62

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[1] Data from Woodmansee and Duncan (1980). These values are from the same plots in two different years.

TABLE 5. Nitrogen and P (g per m^2) in aboveground biomass and the upper 2 decimeters of soil in cheatgrass, shortgrass prairie and wet meadow and tussock meadow communities in western North America and the percent of community N and P in aboveground biomass.

Community	Location	g N/m^2	%	g P/m^2	%
Cheatgrass	WA	195	1.5	10.8	8.9
Cheatgrass	WA	250	2.6	10.0	8.0
Shortgrass[1]	CO	273	3.2	--	--
Wet Meadow[1]	AK	960	0.9	63.2	1.3
Tussock Meadow[1]	AK	964	0.9	48.7	0.3

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[1] Data from Chapin (1980)

allocated to the crowns of the perennial grasses that characteristically dominate the prairie community.

Most of the self-maintained (climax) plant communities in North America are dominated by long-lived perennial plants e.g. conifer forest communities (*Pinus, Abies, Tsuga, Picea,* and others); deciduous forest communities (*Quercus, Carya, Acer, Tilia* and others); perennial grass and graminoid communities (*Bouteloua, Andropogon, Eriophorum, Carex* and others) and desert communities (*Artemisia, Larrea* and others). The cheatgrass communities in Washington and the annual grass communities in California are exceptions to the general rule of community dominance by perennial plants.

The rather limited geographic extent of annual grass communities in North America is a subject of ecological inquiry. It has been postulated that three general survival strategies have evolved in annual plants—*competitive plants, stress tolerant plants* and *ruderal plants* (Grime 1977). In eastern Washington, cheatgrass grows on the steepest south-facing slopes the plant habitats with the most extreme microclimates (Sauer and Rickard 1979, Hinds 1975, Rickard and Warren 1981). This indicates that cheatgrass is a stress tolerant taxon. Cheatgrass is regarded by dryland wheat farmers as a noxious weed because it competes with fall planted winter wheat for soil water and for scarce mineral nutrients. In this respect cheatgrass is a ruderal taxon favored by repetitive soil disturbance by plowing. Rangelands, especially those that have experienced years of overgrazing by livestock to the point where the native grasses and forbs have been weakened or killed, are readily invaded by cheatgrass (Daubenmire 1970). Once cheatgrass becomes established on these overgrazed lands it persists for decades and interferes with the reinvasion by the native perennial plants even when native taxa seed sources are close at hand (Daubenmire 1975, Rickard and Sauer 1982). From this point of view cheatgrass is a competitive taxon. The success of cheatgrass throughout the shrubsteppe region of Washington over the past 100 years or so is attributable to its inherent genetic capacity to be stress tolerant, competitive, and ruderal depending on the history of the particular site.

The exploitation of the available soil water and mineral nutrients by annual plants hampers reinvasion by the native perennial grasses and shrubs at least in the short term, 100 years or so. Perhaps over longer periods of time, native plants will eventually be able to invade well-established annual grass communities and even replace cheatgrass as the dominant taxon. Long-lived, large statured, drought-tolerant perennial taxa that have root systems that can penetrate below the relatively shallow rooting depth of cheatgrass would appear to be the most likely perennial plants to be successful at invading cheatgrass communities (Cline and Rickard 1973).

It seems possible that cheatgrass dominated communities may become even more important in the shrubsteppe region in future years than they are today. The isolated remnant stands of once vast acreages of contiguous native shrubsteppe communities will likely become further modified and even replaced by a variety of man-induced ground disturbances and land management practices aimed at growing crop plants and providing forage for livestock through the planting and maintenance of alien perennial grasses. In this way the once extensive gene pool of native shrubsteppe is depleted and the once contiguous populations become isolated islands. The demise of native species would in the long-term seem to favor the expansion of cheatgrass populations.

Conclusions

Shoot production of annual grass communities is determined in part by the amount of available water in the root zone and the availability of nitrogen and other nutrients. A cheatgrass community at a low elevation site produced more shoot biomass with a higher nitrogen content than a cheatgrass community at a higher elevation. The low elevation community produced more shoot biomass even though it received less precipitation and had less soil water in the root zone at the beginning of the spring growing season. The higher nitrogen concentrations in cheatgrass shoots grown at the low elevation site suggests that nitrogen is more biologically available at this site than it is at the higher elevation. The data also suggests that available nitrogen rather than available soil water is limiting shoot production at the higher elevation.

The success of the alien, cheatgrass in the shrubsteppe region of Washington is attributed to its ability to be stress tolerant, competitive, and ruderal depending on the disturbance history of the particular site.

Acknowledgments

This work was supported by the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

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Received 3 April 1984
Accepted for publication 29 June 1984