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Effects of Soil Compaction by Animal Trampling on Growth Characteristics of *Agropyrum repens* (Case Study: Lar Rangeland, Iran)

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ABSTRACT

Soil compaction resulted from animal trampling play important direct and indirect role in range vegetation growth and development. The goal of this research was to investigate the effects of soil compaction resulted from long term grazing practices in Lar rangelands (Iran) on growth characteristics of *Agropyrum repens* (indicator plant). The experiment was conducted on intact soil samples collected from three range condition sites - the reference site (R), a moderately grazed site (M) and a heavily grazed site (H) in the Lar rangelands (84 km northeast of Tehran, Iran) during the grazing seasons in 2001 and 2002. The results of the experiment showed that some growth characters (plant height, tiller number & plant biomass) were significantly affected by interaction of soil compaction treatments and year (climatic conditions). The tallest plant was obtained in M treatment in 2001 (26.5 cm), while the shortest plant was observed in H→M treatment in 2002. The artificial increment in soil bulk density had a positive effect on tiller number per plant, root bio-mass and whole plant bio-mass (R→M & R→H treatments). The germination percentage and other growth characteristics of *Agropyrum repens* was not significantly reduced due to artificial soil compaction increment. It was concluded that soil compaction due to trampling effects is not the determining factor to explain the less bio-mass and growth performance of high quality plant species in heavily grazed sites (especially if the soil texture is not heavy).

Key Words: Animal trampling; Soil compaction; Growth characteristics; Seed bank reserves; *Agropyrum repens*

INTRODUCTION

Grazing pressure has a simultaneous effect on both soil and range vegetation cover. The interaction effects of different management and environmental factors on range vegetation are so complicated that makes it difficult to distinguish their effects from each other. Many scientists believe that vegetation destruction in rangeland is because of the increment of the grazing pressure and soil deterioration in the same time (Blackburn, 1982; Leck *et al*., 1989). Abdel-Magid *et al.* (1987) reported a 17% reduction in short grass vegetation production under a long term grazing pressure in a simulated trampling experiment. Range vegetation composition and production are the primary factors vulnerable to grazing pressure (McIvor & Gardener, 1990).

Soil physical properties play an important role in the establishment and growth of range plants. Range vegetation grazed by livestock results in compaction of the soil surface which affects soil seed bank germination and establishment. Winkle and Roundy (1991) considered the soil compaction due to grazing as a positive factor to enhance germination percentage in some grasses, while no positive effects of livestock trampling were reported on *Panicum coloratum* germination percentage by Weigel *et al.* (1989). The negative effect of soil compaction because of livestock trampling on plant root development was reported by Otani *et al.* (1994). These authors indicated that the reduction in root development of *Festuca arundinacea* was more severe in lands directly grazed by livestock compared to hand clipped treatments.

The better seed production, and germination results in better vegetation and production in rangelands. Seed production of different range plants under soil compaction conditions was investigated by Krzic *et al.* (2000). They reported that the reduction in vegetation growth under soil compaction conditions is because of the less root development as well as less available plant nutrients and soil moisture. Regeneration and resistance of few range grasses were evaluated under different simulated grazing pressures by Sun (1991). It was found that under different grazing pressures growth and regeneration process of different grasses was much faster in fertile soils compared to the poor soils.

Soil seed bank determines the ultimate vegetation composition of a range site. There is less scientific information available about soil seed bank despite its ecological importance in range vegetation sustainability. The lower seed production of *Artemisia frigida* Willd was reported to be due to heavy grazing, which caused a significant reduction in its seed bank reserves (Bai & Romo, 1997). These authors also indicated that the sustainability of forage production of this plant is depended on its seed bank survival under different grazing pressures.

The interaction between physical, chemical and biological properties and the climate determines the type and kind of range vegetation, its regenerative and carrying capacity. Livestock trampling effects on soil physical properties differs with climatic conditions, geographical position and vegetation conditions. To evaluate the relationship between soil compaction by animal trampling and its effect on soil seed bank and plant growth characteristics, some environmental factors of less importance should be kept constant. To achieve this, the treatments of this experiment were set up in a controlled environment.

Intensive grazing is the major problem of most rangeland areas in Iran. To understand the soil response to different grazing intensities and its effect on range vegetation dynamics, this experiment was conducted on soil samples from the mountainous Lar rangelands of Iran. The goal of this experiment was to evaluate the germination, establishment and early growth characteristics of the indicator plant of the reference area (*Agropyrum repens*) under different soil compactions resulted by long term grazing pressures.

MATERIALS AND METHODS

The Lar watershed has an area of approximately 73000 hectares and is located 84 km to the northeast of Tehran, Iran (51°04´- 51°32´E and 35°48´- 36°04´N). It is a mountainous region and has the highest elevation watershed in Iran at 2400 m above sea level. The area is characterized by deep valleys and an erratic distribution of precipitation. The climate is a temperate semi-arid one with an average annual precipitation of 330 mm and a mean annual temperature of 12°C (1970-2001). Most of the annual rainfall falls during winter (December-February) and spring (March-May) comprising 42.6 and 29.7% of the annual total, respectively. The mean annual wind velocity at 10 m above ground level is 8.2 m s^{-1}.

The textures of the dominant soils are mostly sandy loam with calcareous parent materials. The soil profile is not well developed with a shallow surface (A) layer of 10 to 15 cm and a (B) horizon of 15-20 cm thick. Four land types along with eight land units and 18 land components are recognized in the Lar rangeland soils. The soils have been classified according to their parent materials as well as soil color, soil texture, physical structure, calcium carbonate accumulation in different soil layers, soil depth, EC and pH. There are no limitations placed on plant growth by the pH and EC in the soils. The only limitation to be considered is the high proportion of sand and gravel in the soil texture.

The three main physiognomies of grass, grass-like plants and shrubs characterize the vegetation cover of the Lar watershed. The main species representing the grasses are *Agropyrum repens, Agropyrum intermedium, Bromus tomentellus, Agropyrum spp., Oryzopsis spp., Poa bulbosa, Melica persica, Festuca ovina* and *Dactylis glomerata;* shrubs are mainly represented by *Onobrychis cornut, Astragalus spp.* and *Thymus kotscyanus.* Among grass-like plants, *Carex spp.* is the most important and dominant one as is *Ferula sp*. among perennial herbaceous plants.

Sheep have been herded grazed in Lar ranges by nomads for meat and milk production for over one hundred years. Continuous grazing is practiced extensively from May through to September (the grazing season) every year. Watering points are available in different parts of the range as natural springs and streams. The mean stocking rate varies in different parts of the range according to the bio-mass and water supply available as well as the permission obtained by different tribes from the government authorities. The mean stocking rate in most of the sites in a normal season is one sheep per hectare during the grazing season (late May to late September). However, the number of the sheep grazing in different parts of the range differs according to the area allocated to each tribe.

Sampling procedure. The experimental area (73000 ha) was sub-divided into three sub-sample sites as follows. The reference site (control), which has had no grazing practiced for last 30 years (1970-2001); the moderately grazed site (one sheep per hectare during the grazing period for last 30 years); and the heavily grazed site (more than three sheep per hectare during the grazing period for last 30 years). Sub-sample sites have similar climatic conditions, topography, soil texture and parent materials. All the necessary measurements were recorded for each range condition category in a representing area of five hectares in each site, during the grazing season (late May to late September) in 2001 and 2002.

Each representing sampling area of five hectares was subdivided into four notional strata of 1.25 ha each according to the slope gradient from top to bottom and numbered from 1 to 4. All the samplings were carried out in four replications (one in each stratum). At the end of the grazing period (late May to late September) 12 intact soil samples were collected from each site (Reference (R), moderately grazed (M) and heavily grazed (H)) (a total of 36 intact samples from all experimental sites) using the metal pots of 15 cm diameter and 30 cm height. The standard metal pots were designed and made for this proposes. All the pots were of the same weight and cone shaped at the end, which could be drawn to the soil by pressure. All the soil samples were taken up to 25 cm depth. All the soil samples after being taken were secured by a small holed lead at the bottom. The samples were dried in oven at 75°C for 72 h. To simulate different soil compactions under different animal trampling due to grazing intensity in laboratory, mechanical (pressing machine) and physical (freezing) techniques were employed. The pressing machine was used to increase the soil bulk density from reference site to moderately grazed (R→M) and heavily grazed (R→H) sites as well as moderately grazed to heavily grazed site (M→H) while freezing method was employed to reduce the bulk densities of soil samples from heavily grazed site to moderately grazed (H→M) and reference sites (H→R) and from moderately grazed site to reference site (M→R). The last was to sow five viable *Agropyrum repens* seeds (the indicator plant of the reference area) in each pot to assess its bio-mass production and growth characteristics under different soil compaction treatments and controls (R, M & H). Plants were grown for 180 days and parameters like germination percentage, plant height, shoot and root weight, root surface area, root length and tiller number per plant were recorded for each treatment. The sampling procedures were repeated for two years (2001 & 2002). The data were analyzed based on a completely randomized block design with four replications. The nine soil treatments were as follows:

Intact bulk densities	R	M	H
Converted bulk densities	R→M	M→R	H→R
Converted bulk densities	R→H	M→H	H→M

A compound analysis using MStatC statistical software was employed to analyze the data from two years of the experiment.

To simulate different soil bulk densities and conversions the following procedures were followed:

1. The intact bulk density of the soil samples from different experimental sites were calculated according to formula No. 1.

$D_b = M/V$

Where, D_b: bulk density (g/cm^3)
M: soil sample dry weight (g)
V: soil sample volume (cm^3).

The soil sample volume was calculated by the formula No. 2

$V= (\pi D^2/4)\ H$

Where $\pi = 3.14$
D: sample pot diameter = 15 cm
H: sample height = 25 cm

Actual dry weight (M) of each soil sample was measured after sub-traction the weight of each standard metal container from whole sample weight after drying in the oven.

To convert the bulk density all needed to do was to change the volume of the soil samples either by pressing to increase (e.g. R→H) or by freezing to decrease the bulk density (e.g. H→R). To achieve the proper bulk density in this sense ΔH for each soil sample was calculated. To increase the soil sample volume (positive ΔH) the dry soil samples after being weighted were irrigated to saturate and immediately after the extra water was drained, samples were kept in cold room at -20°C for 72 h. After thawing, if the positive ΔH was more than proposed, it was adjusted by carefully pressing on the sample surface.

RESULTS

Percent seed germination was significantly affected by the soil compaction treatments and year (Table I). The least mean germination percentage was obtained in H→R treatment (35%) and the highest one at R (91%) (Table I), respectively.

Plant height was significantly affected by the soil compaction treatments, year and their interactions (Tables I, II). The least plant height of 4.3 cm was observed in H→M treatment in 2002 and the tallest plants (26 cm) were observed in moderately grazed treatment (M) in 2001.

Tiller number per plant was significantly affected by soil compaction treatments, year and their interactions (Tables I, II). The highest number of tillers was observed in R→H treatment in 2002 and the least of 11.7 heavily grazed site (H) in 2001. Tiller number per plant was 43% higher in 2002 compared to 2001.

Soil compaction treatments and year significantly affected shoot dry weight (Table I). The highest shoot bio-mass of 2370 g/m^2 was observed in M→R treatment while the least shoot bio-mass of 1124 g/m^2 was obtained from heavily grazed site (H) treatment. There was a 27% reduction in shoot bio-mass in 2002 compared to 2001.

Root length was higher in 2001 and decreased by 28% in 2002. Root surface area followed the same trend and decreased by 63% in 2002 (Table I).

Root bio-mass was significantly affected by soil compaction treatments, year and their interactions (Tables I, II). There was a decreasing trend of 47% in this parameter from 2001 to 2002. Plants in H treatment produced the least amount of root biomass of 1350 g/m^2, which increased to 6027 g/m^2 obtained in R→H treatment (mean of two years). However, the highest amount of root bio-mass was produced in R & R→H treatments (8691.3 and 8333.1 g/m^2, respectively) in 2001 and the least root bio-mass was produced in H→M (1325.9 g/m^2) treatment in 2002.

DISCUSSION

Climatic variation in two years of conducting the experiment had no significant effect on % seed germination because the germination happened before the severe changes were happened in both years. There was no significant effect on % seed germination of *Agropyrum repens* due to changes in bulk density in each category (R, M or H). These results are in contrast to findings of other researchers who indicated that the soil compaction due to animal trampling has a positive effect on some grass and forbs germination (Valentine, 1989; Winkle & Roundy, 1991). Based on the present results the decreasing trend in % germination from reference area to heavily grazed site could be explained by other factors like soil fertility, organic matter content and mechanical resistance rather than soil compaction by animal trampling. The higher organic matter in the reference site (3.9%) and moderately grazed site (3%)

Table I. Growth characteristics of *Agropyrum repens* under different soil bulk density treatments in 2001 and 2002 sampled from Lar rangelands, northeast Tehran, Iran

	Plant growth characteristics						
	Germination%	Plant height cm	Tiller No /plant	Shoot biomass g/m^2	Root length cm	Root surface cm^2	Root biomass g/m^2
Year							
2001	69a	22.27a	16.5b	2140a	17.39a	2.63b	4777a
2002	65a	8.85b	28.47a	1566.13b	12.36b	6.15a	2498b
Soil compaction treatments							
Reference site (R)	90 a	17.8b	18.95cde	2050a	14ns	4.1ns	5339ab
Moderately grazed site (M)	70bc	23.9a	28.2b	2185a	15.6ns	5.1ns	4127.5bc
Heavily grazed site (H)	40de	14.25bc	12.2e	1124.4b	13.1 ns	4 ns	1350.5e
R→M	89a	14.9bc	25.7bc	2222.5a	14.6 ns	4.3 ns	5523.5ab
R→H	81ab	9.66c	36.6a	2063.5a	15.8 ns	4 ns	6027a
M→R	58c	16.75b	28.7a	2370.5a	14 ns	4.7 ns	2853cde
M→H	66bc	14.25bc	20.7bcd	2067.2a	15.1 ns	4.3 ns	3526cd
H→R	35e	14.1bc	13.6de	1216.5b	15.7 ns	4.5 ns	1694e
H→M	54cd	14.43bc	16.9de	1377.27b	15.8 ns	4.25 ns	2297de

Within columns for each parameter and treatment, means with the same letter are not significantly different at $p<0.05$

Table II. The interaction effect of different soil bulk density treatments in 2001 and 2002 on some growth characteristics of *Agropyrum repens* soils sampled from Lar rangelands, northeast Tehran, Iran

Plant	*Soil bulk density treatments*								
characteristics	Reference site (R)	moderately grazed site (M)	Heavily grazed site (H)	R→M	R→H	M→R	M→H	H→R	H→M
Plant height (cm)									
2001	24a	26a	23.5a	22.5a	14bc	21.6ab	22.1ab	23a	24.6a
2002	12cd	22.5ab	5c	7.5cd	5.45cd	11.9cd	6.4cd	5.3cd	4.3d
Tiller No./plant									
2001	20.4bc	15cd	11.7e	20.9bc	20bc	16.6c	15.4cd	12.5de	14.9d
2002	17.5bc	41.5a	12.75d	30.5b	53a	40.75a	26b	14.75d	19c
Root biomass (g/m^2)									
2001	8691.3a	5094.4bc	1865.6ef	5778.4b	8333.1a	2932.8cdef	4623.7bcd	2405.3def	3268.6cdef
2002	1987.6ef	3160.1cdef	835.8f	5268.5bc	3720.3bcde	2773.6cdef	2430.2def	1977.6f	1325.9ef

Within columns and rows for each parameter and treatment, means with the same letter are not significantly different at $p<0.05$.

compared to the heavily grazed site (1.7%) helps to explain the ability of these soils to retain more moisture and less mechanical resistance during the growing seasons of 2001 and 2002 in soil samples from reference and moderately grazed sites. Soil compaction in heavily grazed site (M) was accelerated not only because of the high trampling intensity but also because of the lower organic matter content in the topsoil, which adversely affected seed germination.

Plant height of *Agropyrum repens* followed the same decreasing trend of shoot bio-mass from 2001 to 2002 (a reduction by 57% in 2002 compared to 2001). Dramatic climatic changes during early growing stage in 2002 retarded plant growth due to severe cold stress. Erocli *et al.* (2004) has indicated that chilling treatments greatly inhibited both sorghum shoot growth and leaf area.

Bulk density conversion in heavily and moderately grazed soil samples provided with no changes in plant height. However, there were noticeable differences (although not significant) among compacted R→M and R→H treatments compared to control R samples indicating the adverse effect of soil compaction on plant height and growth. The adverse impact of early and high intensity grazing on decreasing the organic matter content of the soil was described by Naeth *et al.* (1991). They also noted that heavy grazing reduces vegetation cover and crumbles the dry litter, accelerating the decomposition process and ultimately reducing soil organic matter content. In reports by Mawendera and Saleem (1997) the reduction in plant growth and height in range species because of shortage in soil organic matter has been reported. This supports the idea that lower soil fertility due to the extremely low organic contents in heavily grazed site is the main reason for shorter plant height and less bio-mass production in all soil samples from heavily grazed site regardless of all conversions applied in bulk density.

Tiller number per plant significantly increased in 2002 because of the better climatic conditions all through the growing season after a cold stress at early growth stage in the same year. The effect of more available moisture and better growing season on more tiller production per plant has been cited by Smith *et al.* (2002). The decreasing trend in tiller number per plant from moderately grazed to heavily grazed soil samples could be because of less favorable growth conditions due to high bulk density (Table I). Significantly higher tiller number in H→M treatment in 2002 well explains the adverse effect of high bulk density in tiller number production per plant (Table II). However, a better soil and root contact provided by R→M and R→H treatments caused a significantly more tillers per plant especially in 2002 where the plants favored a better growing season (Table II). These results indicates that higher bulk density to some extent could be beneficial for better plant growth provided that soil is in a good fertility situation and has enough organic matter content.

Shoot bio-mass per plant followed the same decreasing trend by 28% as plant height from 2001 to 2002 because of less favorable growing conditions in 2002. The erratic monthly mean temperatures along with mean precipitation were the main reasons for poor performance of plants in shoot biomass production in 2002 (Table I & II). Although a good precipitation in early growing season could benefit plant growth, but a severe cold stress caused cold damage and slowed growth of plants in 2002 (Table II) (Ercoli *et al*., 2001).

Conversion in soil bulk densities in different soil categories (R, M & H) provided with no significant differences in shoot bio-mass production in different treatments compared to their own control (Table I & II). This means that less soil compaction is not the determining factor in more biomass production in Reference site compared to Moderately and Heavily grazed sites. This conclusion could be supported by H→R and H→M treatments, which provided with no significant increase in shoot bio-mass production compared to H control treatment. In the natural rangeland conditions in heavily grazed site as the leaf area decreases the evaporation rate from the soil surface increases. There exists a significant relationship between increased livestock trampling, decreased soil organic matter, soil fertility, infiltration rate and increased soil compaction, although it is not a linear one (Naeth & Chanasyk, 1995). The adverse effects of soil compaction due to heavy grazing and livestock trampling on plant growth and biomass production of range species has been reported by other researchers (Severson & Debano, 1991).

A 28% reduction in root length in 2002 compared to 2001, similar to shoot and root bio-mass, indicates a positive correlation between bio-mass production and root length. The severe cold stress during early seedling growth could explain the differences in 2001 and 2002. More available moisture at 0-10 cm soil depth (because of more rainfall during early growth stage) along with cold weather, adversely affected root length in 2002. Available moisture during early growth will usually limit root length because of available moisture in top layer of the soil (Chaichi, 1995).

An increasing trend in root surface area of 63% was observed along with decreasing root length from 2001 to 2002. The thicker roots were a natural response of plants to cold and drought stress all through 2002 growing season. These results are in contrast to findings of Coursolle *et al*. (2000), which has showed decrease trend in root dry mass under freezing condition. However, by keeping all the other variables constant in two years of this experiment, it seems only climatic conditions in 2002 could explain the present results. Long-term trampling pressure, especially in areas with limited amounts of vegetation coverage, can create a layer of hardpan in the sub-soil layer of range sites. This phenomenon is accelerated by a reduction in surface vegetation cover. The lack of vegetation cover, along with the shortage of litter being deposited on the soil surface accelerates the formation of the hardpan layer. The hardpan layer, in turn, acts as a barrier to proper seed germination and root expansion of the young seedlings (Samson, *et al*., 2002).

Root bio-mass production is in fact directly a result of shoot growth. On the other hand freezing condition and available moisture in top soil during early growing season severely retarded root bio-mass production by 43% compared to 2001 (Table I).

In both years of the experiment a decreasing trend in root bio-mass production from R to H treatments are obvious. However, by increasing the soil compaction in soil samples of Reference site (R→M & R→H) a significant increase in root bio-mass production was observed (especially in drier year of 2002). This could be explained by better contact of soil and root in compacted soil samples. Otani *et al.* (1997) reported the adverse effects of animal trampling and soil compaction on *Festuca arundinacea* root growth. While, Winkel and Roundy (1991) have indicated that soil compaction by animal trampling has a positive effect on germination and better establishment of some range species. These results could well support the results of this experiment because of sandy type soil texture and high organic matter content in Reference (R) soil samples.

Soil compaction due to trampling effects is not the determining factor to explain the less bio-mass and growth performance of high quality plant species in heavily grazed sites (especially if the soil texture is not heavy). In such a condition climatic factors as well as some edaphic conditions (organic matter, depth, fertility) other than soil compaction play a significant role in vegetation establishment and production in rangelands.

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REFERENCES

Abdel–Magid, A.H., M.J. Trlica and R.H. Hart, 1987. Soil and vegetation reponses to simulated trampling. *J. Range Management*, 40: 303–6.

Bai, Y. and J.T. Romo, 1997. Seed production, seed rain and seed bank of Fringed sagebrush. *J. Range Management,* 50: 151–5

Blackburn, W., R.W. Knight and M.K. Wood, 1982. Impacts of grazing on watersheds. *Texas Agric. Exp. Sta. Mp*, 1496

Chaichi, M.R., 1995. Grazing management of medic pastures. *Ph.D. Thesis,* p. 240 College of Agriculture University of Adelaide, Australia

Coursolle, C., F.J. Bigras and H.A. Margolis, 2000. Assessment of root freezing damage of two-year-old White spruce, Black spruce and Jack pine seedlings. *J. Forest Res*., 15: 343–53

Ercoli, L., M. Maroitt, A. Masoni and I. Arduini, 2004. Growth responses of Sorghum plants to chilling temperature and duration of exposure. *European J. Agron.,* 21: 93–103

Krzic, M., K. Broersma, D.J. Thompson and A.A. Bomke, 2000. Soil properties and species diversity of grazed crested wheat-grass and native rangelands. *J. Range Management*, 53: 353–8

Leck, M.A., R.L. Simpson and V.T. Parkerson, 1989. *Ecology of Soil Seed Bank*. Publication Academic Press, USA

Mawendera, E.J. and M.A.M. Saleem, 1997. Infiltration rates, surface runoff, and soil loss an influenced by grazing pressure in the ethiopian highlands. *Soil Use and Manage.,* 13: 29–35

McIvor, J.G. and C.J. Gardener, 1990. Soil and vegetation characteristics of dry tropical rangeland for predicting pasture regeneration in exclosures (North Queensland). Australian ecosystems: 200 years of utilization, degradation and reconstruction. Chipping norton, N.S.W. (Australia). *Ecolog. Society of Australia,* pp. 273–7

Naeth, M.A. and D.S. Chanasyk, 1995. Grazing effects on soil water in Alberta foothills fescue grasslands. *J. Range Manage.,* 48: 528–34

Naeth, M.A., A.W. Bailey, D.J. Pluth, D.S. Chanasyk and R.T. Hardin, 1991. Grazing impact on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. *J. Range Manage.,* 44: 113–7

Otani, I., Y. Takahashi, S. Uozumi, Y. Yoden and R. Igarashi, 1994. Influences of cutting and grazing tall fescue sward on red-yellow soil on the grass root and soils. *Bull. Chugoku Nat. Agric. Exp. Station,* 14: 69–89

Otani, I., Y. Takahashi, K. Hagino, S. Uozumi, Y. Yoden and R. Igarashi, 1997. Influences of trampling on pasture plants root and ventilating system. *Bull. Chugoku Nat. Agric. Exp. Station,* 17: 53–74

Sun, D., 1991. Plant resistance to and recovery from trampling and soil fertility of four [sub-tropical] grasses. *Australian Parks and Recreation*, 27: 28–30, 32–3

Samson, B.K., M. Hasan and L.J. Wade, 2002. Penetration of hardpans by rice lines in the rain fed lowlands. *Field Crop Res*., 76: 175–88

Severson, K.E. and L.F. Debano, 1991. Influence of Spanish goats on vegetation and soils in Arizona chaparral. *J. Range Manage*., 44: 111–7

Smith, S.E.D. Fendenheim and R. Mosher, 2002. Seed Production in sideoats grama populations with different grazing histories. *J. Range Manage.*, 53: 550–5

Valentine, J.F., 1989. *Range Development and Improvments*. Publication Academic press San Diego, California

Weigel J.R., V.K. Winkle and B.A. Roundy, 1989. Effect of cattle trampling and mechanical seedbed preparation on grass seedling emergence. *J. Range Manage*., 44: 8–25

Winkel, V.K. and B.A. Roundy, 1991. Effects of cattle trampling and mechanical seedbed preparation on grass seedling emergence. *J. Range Manage.*, 44: 176–80

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