Interrelations of the Physical Properties of Coppice Dune and Vesicular Dune Interspace Soils with Grass Seedling Emergence

M. K. WOOD, W. H. BLACKBURN, R. E. ECKERT, JR., AND F. F. PETERSON

Highlight: Vesicular soil surface horizons are found throughout the arid and semiarid areas of the world associated with sparse vegetation. In the Great Basin this horizon occurs in the surface 5 or 8 cm of dune interspace soil. Vesicular horizons are characterized by a high silt content, low organic matter, poor aggregation, and low infiltration rates. Our intent was to study the influence of organic matter removal on vesicular development and to determine the effect of a vesicular horizon on seedling emergence. Removal of organic matter from coppice dune soil resulted in a poorly aggregated vesicular soil with properties similar to those of the untreated interspace soil. Crested wheatgrass and squirreltail seedling emergence was poor and seedling stress was high in vesicular dune interspace soil.

Coppice dunes are aeolian deposits under and around shrubs and perennial bunch grasses (Fig. 1). These dunes are formed by deposition of silt and very fine sands from river flood plains and from the recently dried Pleistocene lakes or playas throughout the Great Basin. Dune interspace is defined as the area between coppice dunes (Melton 1940; Stuart et al. 1971; and Blackburn 1975). Surficial vesicular horizons occur in arid and semiarid parts of the world with sparse vegetation. Volk and Geyger (1970) stated that in warm, arid regions of southern Spain, Morocco, and southwest Africa, barren areas free of vegetation occurred in a mosaic-like pattern, although lack of vegetation could not be attributed to low precipitation, soil salinity, or overgrazing. The soil surface had a vesicular horizon that apparently prevented penetration of precipitation. In the Great Basin, this horizon is typically associated with a northern desert shrub, salt desert or southern desert shrub overstory, and sparse understory vegtation. Vesicular horizon occurs in the surface 5 or 8 cm of dune interspace soil (Fig. 2), and seldom occurs in well-aggregated coppice dunes. Vesicular development is generally strongest in the middle of the dune interspace and becomes weaker nearer to the coppice dune areas of regular organic matter addition.

Springer (1958) reproduced vesicular pores similar to those occurring naturally by wetting and drying sieved soil samples from a vesicular horizon. As water infiltrated into the sieved soil materials, the particles became rearranged, closely packed, and air collected into larger pores. Soil particles and voids were continually rearranged by repeated wetting and drying, while air bubbles moved toward the top of the soil sample and escaped. He concluded that vesicular porosity was unstable, transitory, and quickly reformed in certain soils.

Fig. 1. *Dune interspace soil between big sagebrush* (Artemisia tridentata *Nutt.) plants and coppice dune soil associated with the plants.*

Miller (1971) studied vesicular pore formation under furrow irrigation in Washington and speculated that a platy structure developed first. He found that under saturated, unstable conditions, the pressure of air entrapped in pores was sufficient to form the cavities between platelets into spheres. Additional air would be trapped in the soil with each wetting and drying cycle.

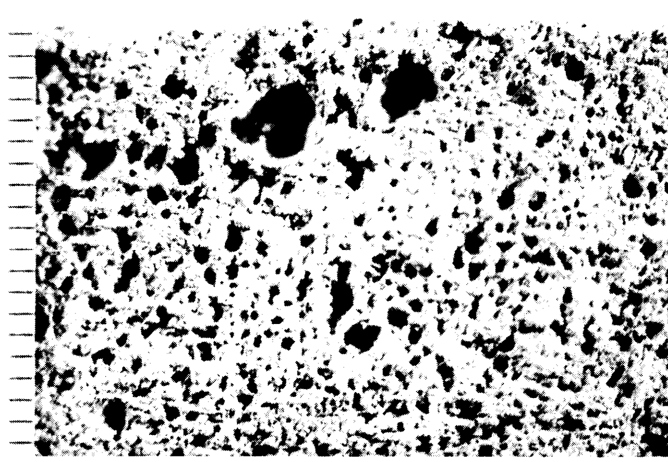

Fig. 2. *Vesicular horizon showing platy structure and vesicular porosity; scale division is 1.0 mm.*

Authors are graduate teaching assistant, and associate professor of watershed management, Range Science Department, Texas A&M University, College Station; range scientist, pasture and range management research, U.S. Department of Agriculture, Agriculture Research Service, Renewable Resources Center, University of Nevada, Reno; professor of soil science, Plant, Soil and Water Science Division, University of Nevada, Reno.

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Under wet, fluid conditions, the small vesicles should merge into larger ones since the surface area per unit volume decreased as the vesicles enlarged. These theories may be substantiated by measuring any decrease in bulk densty with vesicular formation and enlargement during repeated wetting and drying. Miller's study also indicated that vesicular horizons were commonly high in silt (40 to 70%). Application of heat to the soil surface during drying periods also had no effect on vesicle formation.

Blackburn (1975) found that vesicular dune interspace soil had an exceedingly low infiltration rate, sometimes 3 to 4 times lower than coppice dune areas. Likewise, greater sediment loss came from these interspace areas. He also observed dune interspace soil to have a shallower surface horizon, a lower organic matter content, a higher bulk density, and a higher percent silt than the coppice dune soil. Dune interspaces have massively crusted, over structured platy A horizons as compared to the granular structure of the coppice dunes. Vesicular horizons are the major factor contributing to low infiltration rates and sediment production from large areas of arid and semiarid rangelands.

Several questions arise as a result of these studies. Will the removal of organic matter from coppice dune soil produce a vesicular soil similar to the interspace soil? What is the influence of vesicular interspace soil on seedling emergence? The objectives of this study were to characterize some of the physical attributes of coppice dune and vesicular dune interspace soils and to determine the effect of a vesicular horizon on seedling emergence.

Methods and Materials

Soils from Coils Creek Watershed (Table 1) were used to study vesicular horizon properties and their influence on seedling emergence. The soils are fine, montmorillonitic, mesic, Xerollic Nadurargids. Soil samples were sieved through a 2-mm screen. Greenhouse experiments were conducted with pots 10 cm in diameter and 8 cm high, unless otherwise stated. Soils were watered to saturation.

Seedling Stress during Emergence

Seedling stress during emergence was determined in untreated coppice and interspace soils. Twenty-four pots were filled with 6 cm of coppice soil and another 24 with 6 cm of interspace soil. Within each soil type, 12 pots were watered every 3 days, and 12 pots were watered every 6 days. Within each watering cycle, six pots were planted ith 10 crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult) seeds, 2.5 cm deep, and six pots ith 10 squirreltail (*Sitanion hystrix* (Nutt.) J. G. Sm.) seeds.

Total emergence was determined after 3 weeks and each seed or seedling was examined and given a stress rating as follows:

1. No stress—Coleoptiles were longer than 2.5 cm, straight, and well developed.
2. Slight stress—Coleoptile length was > 2.5 cm but the coleoptile was slightly curved or wavy.
3. Moderate stress—Coleoptile length was < 2.5 but greater than 1 mm. Coleoptile had prominent wavyness.
4. Heavy stress—Coleoptile length was < 2.5 cm but greater than 1 mm. Coleoptile growth was retarded.
5. Extreme stress—Germination was initiated, but coleoptile grew < 1 mm.
6. Failure—Seed did not germinate or coleoptile did not break the seed coat.

Organic Matter Removal

Two liters each of coppice dune and dune interspace soil were boiled in hydrogen peroxide (H_2O) to oxidize organic matter. Untreated soil and soil boiled in water were used as controls. Percent organic matter content was determined by the Walkley Black method (Black 1965). Soil from each treatment was also evaluated for bulk density and crust strength by the modulus of rupture technique (Black 1965) after four saturation-drying cycles. These measurements are extremely useful for characterizing specific physical properties and as manifestations of soil structure (Taylor and Ashcroft 1972). Soil from each treatment was placed in 4-cm dia by 4-cm pots and planted with five crested wheatgrass seeds. A set of pots from each treatment was watered every day and another set was watered every 2 days. Seedling emergence was determined after 3 weeks.

Statistical inferences were based on a one-way analysis of variance and mean separation by Duncan's multiple range test (Steel and Torrie 1960).

Table 1. Soil surface horizon parameters for coppice dune and dune interspace soils of the big sagebrush community, Coils Creek Wastershed, Nev.

Parameter	Coppice dune	Dune interspace
Depth (cm)	7	4
Color		
Dry	10 YR 5/3	2.5Y 6/2
Moist	10 YR 4/2	2.5Y 4/2
Texture		
Sand	55	44
Silt	33	36
Clay	12	20
Structure	Weak, very fine subangular blocky over weak, very fine platy	Weak, massive over weak, medium fine platy
Consistence		
Dry	Slightly hard	Slightly hard
Moist	Very friable	Friable
Wet	Nonsticky/nonplastic	Nonsticky/slightly plastic
pH 1:5	8.1	7.7
$CaCO_3$	Noneffervescent	Noneffervescent
Roots	Abundant	None
Boundary	Abrupt/smooth	Abrupt/smooth
Coarse fragments % vol.	<5	<5
Aggregate stability	Stable	Unstable

Results and Discussion

Seedling Stress during Emergence

Significantly more seedlings emerged in the coppice dune than in the dune interspace soil (Table 2). Differences in emergence were not significant between watering treatments, although a trend toward lower emergence percentages was observed with less frequent watering. Crested wheatgrass seedling emergence was 88% in untreated coppice dune soil and 15% in untreated dune interspace soil watered every 3 days. When watered every 6 days, 80% emerged in coppice soil and 3% emerged in interspace soil. Similar trends were observed for squirreltail, although emergence percentages were lower than for crested wheatgrass.

Crested wheatgrass and squirreltail exhibited the least seedling stress in coppice dune soil watered every 3 days (Table

Table 2. Mean percent emergence of crested wheatgrass and squirreltail seedlings planted in coppice and interspace soils watered every 3 or 6 days.

Soil	Watering cycle (days)	Emergence (%)[1] Crested wheatgrass	Squirreltail
Coppice	3	88 a	58 a
	6	80 a	45 a
Interspace	3	15 b	5 b
	6	3 b	0 b

[1] Means within a column followed by same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Table 3. Mean stress symptoms exhibited by crested wheatgrass and squirreltail seedlings in coppice and interspace soils watered every 3 or 6 days.

Soil	Watering cycle (days)	Stress rating[1]	
		Crested wheatgrass	Squirreltail
Coppice	3	1.57 a	2.30 a
	6	1.85 a	2.35 a
Interspace	3	3.83 b	4.20 b
	6	4.70 c	5.60 c

[1]Means within column followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

3). There was no significant difference due to watering treatment on stress of either species in coppice dune soil. Seedlings of both species grown in interspace soil and watered every 6 days showed heavy and extreme stress. Squirreltail stress values were slightly higher than those for crested wheatgrass, regardless of treatment. Crested wheatgrass and squirreltail in coppice soil watered every 3 days showed no stress to moderate stress (Fig. 3). A high percentage of the crested wheatgrass and

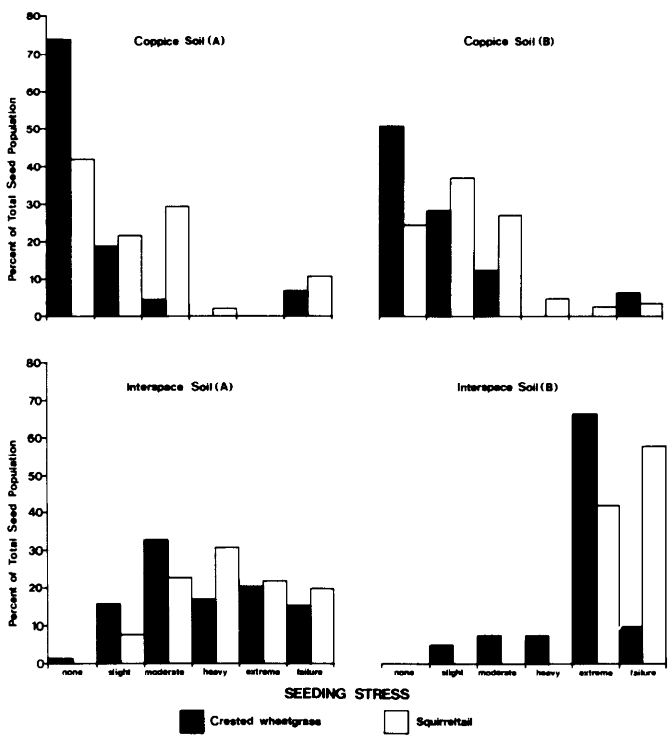

Fig. 3. *Percentage of crested wheatgrass and squirreltail seedlings exhibiting various degrees of seedling stress when planted in coppice dune and dune interspace soils and watered every 3(A) and 6(B) days.*

squirreltail seedlings in dune interspace soil exhibited symptoms of moderate to extreme stress. When watered every 6 days, crested wheatgrass and squirreltail in coppice dune soil were not stressed or were moderately stressed. However, a large percentage of seedlings of both species planted in dune interspace soil exhibited symptoms of extreme stress, and some seeds did not germinate.

Organic Matter Removal

When dune interspace soil was watered daily, there was no significant difference between treatments on emergence (80 to 95%) of both species, and percentage emergence (80 to 96%) was similar to coppice dune soil treatments. However, crested wheatgrass emergence (44%) was significantly reduced in untreated dune interspace soil watered every 2 days as compared to treated soil. No seedlings emerged in hydrogen peroxide-treated soils subjected to the 2-day watering cycle. Vesicular soil kept moist exerted little resistance to seedling emergence; however, once dried, these soils crusted and retarded seedling emergence. Emergence of seedlings in coppice dune soil with the organic matter removed to the level of that in interspace soil (Table 4) was retarded to the same extent as emergence in interspace soil.

Table 4. Mean percent organic matter in coppice and interspace soils untreated, boiled in water (H_2O), or boiled in hydrogen peroxide (H_2O_2).

Treatment	Mean organic matter (%)	
	Coppice	Interspace
None	5.10 d	1.31 b
Boiled in H_2O	4.63 c	1.14 a
Boiled in H_2O_2	1.14 a	1.09 a

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Soil Physical Properties

Bulk Density

Boiling coppice dune and dune interspace soils in water did not significantly change the bulk density; likewise, boiling dune interspace soil in hydrogen peroxide did not alter the bulk density. After the organic matter content was reduced by boiling in hydrogen peroxide, the bulk densty of coppice soil (1.20 g/cc) was similar to that of dune interspace soil (1.23 g/cc).

Modulus of Rupture

After four saturation-drying cycles, the hardness or modulus of rupture of untreated coppice dune soil with 5.1% organic matter was 0 millibars, and untreated dune interspace soil with 1.31% organic matter was 45 millibars. After four saturation-drying cycles, the hardness of coppice dune soil boiled in hydrogen peroxide with 1.14% organic matter was 110 millibars, and interspace soil boiled in hydrogen peroxide with 1.09% organic matter was 210 millibars. Gifford and Thran (1969) reported a maximum emergence force of 6 millibars for tall wheatgrass (*Agropyron elongatum* Host.), and Williams (1956) gave maximum emergence forces of 15 millibars for alfalfa (*Medicago sativa* L.), 23 millibars for crimson clover (*Trifolium incarnatum* L.), and 24 millibars for rose clover (*Trifolium hirtum* All.). Cary and Evans (1974) reported that the moduli of rupture ranged from 0 to 50 millibars for productive agriculture soils with no specific crusting problems. Vesicular horizons are low in organic matter, poorly aggregated, and unstable when near saturation (Miller 1971; and Blackburn 1975). Areas of well developed vesicular horizons are commonly devoid of vegetation. The few plants present are usually annual weeds and occur in the polygonal cracks. Contrary to the opinions of Evenari et al. (1974), vesicular horizons inhibit seedling emergence as evidenced by stress symptoms of crested wheatgrass and squirreltail seeds planted in a vesicular horizon (Tables 2 and 3).

Coppice soil with most of the organic matter removed resulted in a poorly aggregated vesicular soil similar to the untreated interspace soil. Organic matter apparently plays a critical role in preventing vesicular horizon development.

From these experiments and from field experiences, we postulate that the soil becomes vesicular when rangelands in good condition, but with the soil potential to become vesicular, are overgrazed to the extent that herbaceous vegetation is destroyed in the interspaces between shrubs. The organic matter in the interspace soil is reduced by rapid oxidation, and with no addition of organic matter, vesicular horizon development expands and strengthens. This tends to lower the potential of the site by reducing the infiltration rate and increasing the stress placed on seedlings. This type of retrogression results in a mosaic type vegetation, consisting of rather unpalatable shrubs associated with the coppice dune surface soil and relatively vegetation-free spaces associated with vesicular dune interspace areas. Millions of hectares of our arid and semiarid rangelands are in this poor condition mainly because of past livestock abuse. Since it will be difficult, if not impossible, to revegetate the vesicular dune interspace areas naturally or through grazing management, use of some mechanical treatment will probably be necessary to rehabilitate these areas.

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