Frost Heaving of Grass and Brush Seedlings on Burned Chamise Brushlands in California

H. H. BISWELL, A. M. SCHULTZ, D. W. HEDRICK, AND J. I. MALLORY

Hedrick is Assistant Professor, Oregon State College, Corvallis, Oregon; others are Professor, Associate Specialist and Junior Specialist, respectively, School of Forestry, University of California, Berkeley, California

FROST heaving has been observed to be a frequent cause of failure to obtain satisfactory stands of grass from reseeding burned brushlands in California. In some cases heaving of grasses and legumes is very severe. The influence of frost heaving on brush seedling establishment is not so spectacular as on grasses and legumes. Nevertheless, it has an important influence in some years on the number and type of young brush plants that become established. The frost heaving situation needs to be recognized and an effort made not only to develop techniques in reseeding and fertilizing to reduce loss from this factor, but also to determine what species are best adapted to the different sites where frost heaving is severe.

Records of conditions under which frost heaving occurs and measurements of its severity during the four winters 1948–49 to 1951–52 were made in burned chamise brushlands in Lake County, California, three to eight miles west of Clear Lake. Frost heaving in this area has been observed to be more severe than in many other areas. However, some heaving of reseeded grasses and brush seedlings has been observed in widely scattered areas of California.

Literature Review

A review of literature did not disclose any data on the extent to which grasses and brush seedlings are destroyed by frost heaving. However, studies on the nature of frost heaving and the factors that cause it have been made and reported by several workers. Some information is available on practices helpful in preventing frost heaving.

Taber (1930) reported that freezing causes ice crystals to build up in the soil. Water is pulled upward through the soil where layers of segregated ice are formed. It is this growth of crystals from underlying water which results in excessive heaving of soil rather than the change in volume that occurs when water freezes in the soil interspaces. Freezing tends to concentrate water near the soil surface and the segregation of ice layers is accentuated by a high water content. Thus, repeated freezings after thawings result in greater and greater segregation (Taber, 1929). Taber found the lifting force of heaving to be as much as 200 lbs. per square inch of soil.

Some of the factors influencing frost heaving are size and percentage of soil interspaces, size of soil particle, water content of the soil, rate of cooling, and depth of freezing (Taber, 1929). Sandy soils heave less than silts and clays because sand slows the upward movement of water by capillarity and thus inhibits the formation of ice layers. Saturated soils heave more readily than drier ones, especially where the water content is high below the frost line. The formation of ice crystals is favored by a slow rate of freezing; high organic content and light color in the soil are associated with slow changes in temperature. The depth of freezing limits the amount of surface heaving that can take place.

Anderson (1947), in a study of freezing of bare soil and soils supporting vegetation, found that the length of the winter freezing period and the frequency and depth of freezing were all decreased by vegetation. A living grass cover would limit the depth of freezing to about one-half inch on sites which would freeze to 2.5 inches when bare. Several workers (Anderson, 1947; Atkinson and Bay, 1940; Barnett, 1937; Belotelkin, 1941) have reported that snow greatly retards heaving.

McCool and Bouyoucos (1929) suggest that frost heaving can be lessened by planting early and fertilizing. The early planting and fertilizing enables the plants to develop a strong and wide spreading root system before the frost heaving period and the plants are not pulled out of the ground so easily. In addition, if heaving does take place, the chances are greater for the plants being supplied with water until new root growth takes place. The large top growth also tends to protect the ground and results in more uniform temperatures and less freezing and thawing. McCool and Bouyoucos also found that frost heaving is usually more severe on poorly drained than on well drained soils, and recommend draining wet lands in some manner wherever possible.

Results

The soils in the study areas near Clear Lake, California, are derived from consolidated sedimentary rocks. On south exposures they may be less than 12 inches deep, light brown in color, moderately acid, and clay to clay loam in texture. On north exposures the soils are similar but range in depth from 12 to 24 inches. The upper inch or two of soil in the study areas is rather loose after fires.

The nearest standard weather station to the study areas is at Lakeport on the shore of Clear Lake. The weather records there for the winter months of three years are contained in Figure 1; also indicated are the periods of greatest frost heaving. A limited number of measurements with thermographs on the study areas between December 8, 1951 and February 7, 1952 showed the temperatures there to average 5° F. higher than those in Lakeport during clear weather, 0.5° F. lower during rainy weather, and 1° F. lower during snowy weather. The thermograph shelters were on the ground. The weather was clear for about half of this two-month period. On south exposures the temperatures averaged 4° F. warmer than those on north exposures during clear weather, with an extreme of 12° F. warmer. During rainy weather the south exposures averaged only 1.5° F. warmer than the north exposures. The temperatures on the east and west exposures were between those on the north and south slopes, with the east somewhat more similar to the north exposure and the west more similar to the south exposure. The temperatures on the four exposures to the nearest whole degree Fahrenheit during the period of measurements are shown in Table 1.

Day and night temperatures during periods of rain and snow fluctuated only 5 to 6° F., while during clear weather they fluctuated 13 to 18° F. Frost heaving was greatest during clear weather when the temperatures fluctuated most, causing notable freezing and thawing. This usually followed rainy periods when the soil was wet.

Frost heaving exerts a great pulling force on roots. So strong is this force that tap roots of one-year-old brush seedlings

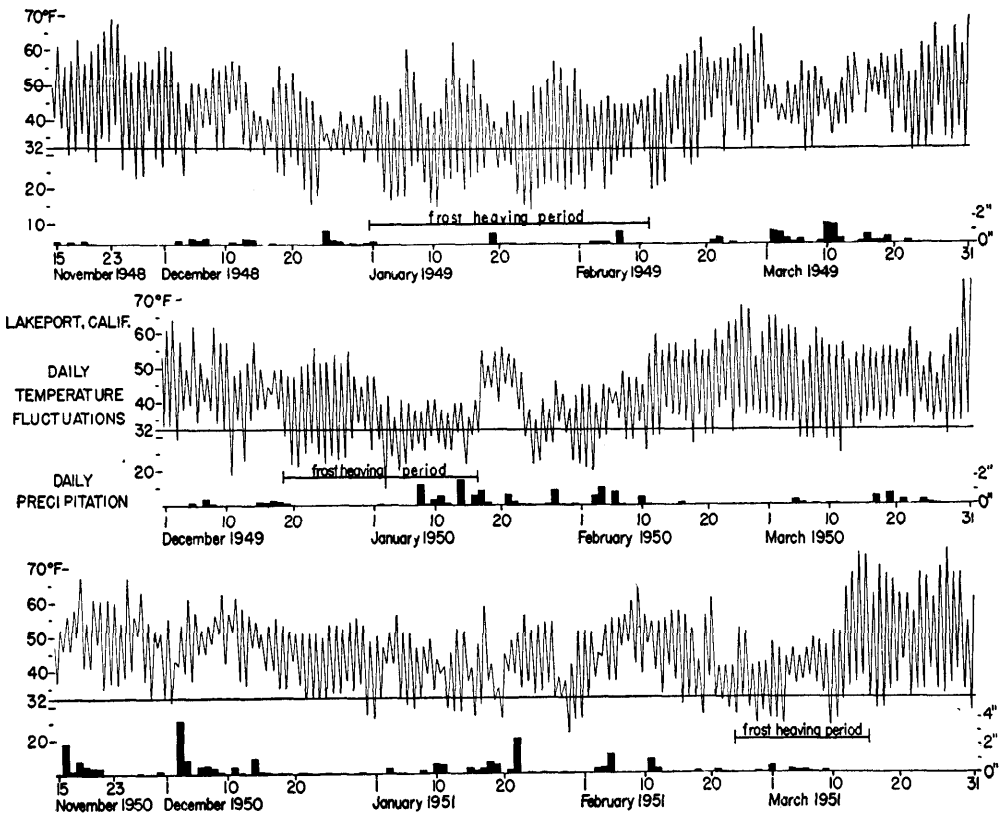

FIGURE 1. Graph shows daily maximum and minimum temperatures during three of the winter periods when frost heaving was observed. As indicated, most frost heaving of reseeded grasses takes place during alternate freezing and thawing of the soil, mostly during clear weather.

TABLE 1

Fahrenheit temperatures on four exposures during clear and rainy weather between Dec. 8, 1951 and Feb. 7, 1952, Lake County

	EXPOSURES							
	North		South		East		West	
	Clear	*Rainy*	*Clear*	*Rainy*	*Clear*	*Rainy*	*Clear*	*Rainy*
Average maximum temperature	47	42	53	44	49	41	52	41
Average minimum temperature	34	36	36	38	35	36	34	36
Average daily temperature	40	39	44	41	42	38	43	38
Number of days temperature dropped below freezing	10	6	7	2	8	7	11	7

extending to depths of three or four feet were observed to be broken four to six inches below the soil surface. Alternate freezing and thawing for several days in succession may lift the seedlings completely out of the soil. Because the roots branch downward they will not go back in place as the soil particles subside on thawing. Plants may have their roots broken by only one or two freezes, but unless heaved out completely they sometimes take root again. However, both grass and brush seedlings are most severely affected in the stages of early emergence when they are most susceptible to heaving and subsequent drying of their delicate root systems. The alternate freezing and thawing seems to be an important factor in heaving of seedlings. In the more continuously cold areas, where the soil freezes and remains frozen during most of the winter, or where the ground is covered by snow, heaving of seedlings is not so severe.

Temperatures for the four winters were not compared to long-time averages, but residents in the area considered the winters of 1948–49 and 1949–50 to be among the most severe of their recollections in causing frost heaving. The winters of 1950–51 and 1951–52 were milder and considered more normal. In the winter of 1948–49 frost heaving was severe in many areas of California, the seedlings of many annual plants having been heaved out.

Extent of Frost Heaving of Reseeded Grasses

The results of heaving are given separately for each year since they were not always taken in the same way and therefore cannot be averaged.

Winter of 1948–49—About 500 acres of a wildfire burn were reseeded in September 1948 to a mixture of domestic ryegrass (*Lolium multiflorum*), tall fescue (*Festuca arundinacea*), orchard grass (*Dactylis glomerata*), and bur clover (*Medicago hispida*) at the rate of 7 pounds per acre. Germination after rains in September was limited to depressions and areas with a good mulch cover. General germination was not effected until heavy rains came in the latter part of November, after which an excellent stand of seedlings appeared. Some frost heaving in late December followed by general heaving in January caused an estimated 99 percent of the seedlings to be heaved out of the soil. Only a few seedlings of annual ryegrass that had emerged after the September rains, and had developed root systems extending down to six inches, survived the extreme daily fluctuations in temperature. Examinations in the spring and summer of 1949 revealed this attempt at reseeding to be an almost complete failure. Frost heaving was the primary cause of this loss.

Winter of 1949–50—Many species were seeded in September 1949, on various exposures in freshly burned areas. Maximum germination was recorded on January 3, shortly before a period of severe frost heaving. The extent of this damage was determined by counting both well rooted seedlings and those heaved out on 40 randomly placed square-foot plots.

Frost heaving was considerably less on the south-facing than on the north-facing exposures (Table 2). Plants on the south exposures were a little further developed than those on the north exposures and this may account for some of the difference. Also, the differences may have been due in part to the fact that the soils on the south-facing slopes were shallower than those on the north-facing slopes and did not contain as much moisture. On both exposures, the legumes were heaved more severely than the grasses. Of the grasses, hardinggrass showed the least amount of heaving, whereas ryegrass, orchardgrass, prairie brome, and soft chess showed the most.

Winter of 1950–51—In early October a freshly burned area was seeded to a mixture of one-half hardinggrass and one-half smilo at the rate of 8 pounds per acre. Abundant rainfall shortly after the seeding produced excellent germination by the latter part of November. As the winter was wet and mild, growth was good and by the middle of March root systems of both species extended to depths of 12 to 15 inches. Nevertheless, frost heaving of smilo was rather severe in late February and early March. The amount of frost heaving as determined by sampling 13 one-square-foot plots on each exposure on March 16 is shown in Table 3.

In this case well established hardinggrass plants were not heaved by moderate freezes, whereas smilo was severely affected. As in the past two years, frost heaving was more severe on northern than on southern exposures.

An examination of the root systems on March 16 revealed the main roots of hardinggrass to be considerably heavier and stronger than those of smilo, the latter being fine and rather delicate. Apparently the heaving action broke the roots of smilo but had little or no damaging effect on the hardinggrass.

TABLE 2

Percentages of seedlings of 14 reseeded species heaved by frost on north and south exposures during winter of 1949 to 1950

SPECIES	SEEDLINGS PER SQ. FT. BEFORE HEAVING		PERCENTAGES OF SEEDLINGS HEAVED	
	North-facing slope	South-facing slope	North-facing slope	South-facing slope
Hardinggrass *Phalaris tuberosa*	14	2	47	0
Tall fescue *Festuca arundinacea*	18	4	50	8
Smilo *Oryzopsis miliacea*	7	2	59	27
Purple stipa *Stipa pulchra*	3	2	59	30
Mountain brome *Bromus marginatus*	15	6	67	9
Wild oats *Avena fatua*	7	1	70	0
Tall oatgrass *Arrhenatherum elatius*	13	5	70	18
Harlan brome *Bromus stamineus*	7	3	73	0
California ryegrass *Lolium* sp.	33	17	77	0
Domestic ryegrass *Lolium multiflorum*	10	4	77	9
Orchardgrass *Dactylis glomerata*	22	3	80	19
Prairie brome *Bromus catharticus*	7	4	85	23
Soft chess *Bromus mollis*	5	4	88	20
Legume mixture	10	3	99	66

Winter of 1951–52—On October 18, 1951, a freshly burned area in Lake County was seeded to several grasses. Frost heaving was measured on west-and north-facing slopes by determining the number of marked plants heaved from December through March. The results were similar to those of previous years (Table 4).

emergence and mortality during the period of frost heaving.

The counts of brush seedlings on 13 square feet of each treated exposure are shown in Figure 2. On and after January

TABLE 3

Extent of frost heaving of hardinggrass and smilo seedlings during winter of 1950–1951

SPECIES	EXPOSURE					
	Northwest			Southeast		
	Plants rooted	*Plants heaved*	*Percent heaved*	*Plants rooted*	*Plants heaved*	*Percent heaved*
Hardinggrass	49	0	0	14	0	0
Smilo	77	223	74	156	67	30

TABLE 4

Extent of frost heaving of grass seedlings during the winter of 1951–1952

SLOPE AND SPECIES	NUMBER OF PLANTS	PERCENTAGE HEAVED		
		December	March	Total
North-facing slope				
Perennial rye-grass, *Lolium perenne*	165	51	33	84
West-facing slope				
Domestic rye-grass	19	16	16	32
Perennial rye-grass	15	27	27	53
Soft chess	11	36	45	81
Orchardgrass	64	39	44	83

Frost Heaving of Brush Seedlings

Three small areas of chamise brushland, each about one-fourth acre in size, were cleared near Lakeport, California, in the summer of 1950. Mil-acre plots on these were given various burning treatments in the summer and fall of 1950 to check on brush seedling emergence and establishment. Square-foot plots within these treated areas were used to follow the germination of brush seedlings throughout the winter and spring of 1950–51. Counts were made weekly, starting December 26, 1950, to follow

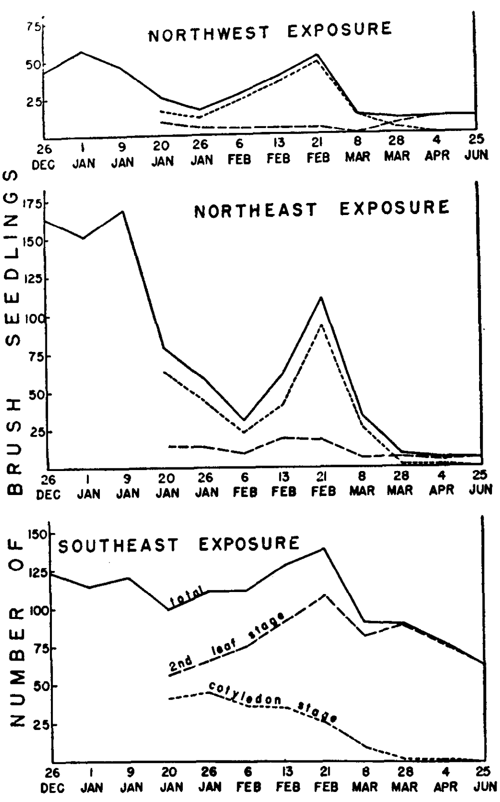

FIGURE 2. Loss of brush seedlings resulting from frost heaving in the cotyledon and the second leaf stages on three exposures during the winter of 1950–1951. The fluctuations up to March 28 were due chiefly to frost heaving. The seedlings are chamise and wedgeleaf ceanothus.

20, the seedlings were classified as to whether they were in the cotyledon or second leaf stage. From these data it is evident that the loss from frost heaving was principally in the cotyledon stage and also that the greater effect of frost heaving on northern as compared with southern exposures holds true for brush as well as grass seedlings.

Again in March, 1952, several burned areas were sampled for brush seedlings. This was just at the time when frost heaving was occurring. As before, the southfacing slopes had the lowest losses from heaving (Table 5). At this time the firmly rooted chamise (*Adenostema fasciculatum*) seedlings were in an advanced stage of development as compared with the wedgeleaf ceanothus (*Ceanothus cuneatus*) seedlings. The latter were mostly in the cotyledon stage. However, seedlings of both species in the cotyledon stage heaved out to about the same extent.

The seedlings of yerba santa (*Eriodictyon californicum*), a plant common on chamise brushlands, were notably absent in the early samplings. Yerba santa seedlings emerge later than do either chamise or wedgeleaf ceanothus seedlings, thus in some years escaping the severe frost heaving period. The combination of a severe winter and this difference in time of emergence of brush seedlings can have a profound effect on the composition of brush stands after a fire.

On the basis of 60 widely scattered one-square foot samples taken in July there were 13 chamise seedlings, 2 wedgeleaf ceanothus seedlings and 57 seedlings of yerba santa per 100 square feet in the same general area covered by the samples in Table 5.

TABLE 5

Extent of frost heaving of brush seedlings during the winter of 1951–1952 on areas burned in the summer of 1951

SLOPE FACING	AREA SAMPLED (SQ. FT.)	CHAMISE		WEDGELEAF CEANOTHUS	
		Number of seedlings	Percent heaved	Number of seedlings	Percent heaved
West	9.5	54	85	4	100
North	9.5	11	82	28	93
East	7.5	11	64	17	59
South	7.5	17	35	7	43
All slopes	34.0	93	73	56	77

Effects of Mulch on Frost Heaving

The extent of frost heaving of grass or brush seedlings is reduced by any ground cover which ameliorates the extremes of low and high temperatures. On chamise land good cover occurs when mature brush has been broken down and is lying flat on the soil surface or when a fair amount of herbaceous vegetation is present.

Two adjacent areas of chamise brush with similar direction and degree of slope were seeded to a mixture of 4 pounds of soft chess and 2 pounds of rose clover (*Trifolium hirtum*) per acre in October, 1951. One of the areas had been control burned in July, 1951; the other had been bulldozed with the blade about 6 inches above the soil. There was practically no herbaceous vegetation under the brush in either area before treatment.

In June, 1952, each of the two areas

was sampled intensively with 300 points using a point analyzer. The results obtained are shown in Table 6.

The mulch consisted almost entirely of broken tops of old chamise plants. On the bulldozed plot 81 percent of the mulch consisted of dead leaves and stems less than one-fourth inch in diameter; on the burned plot only 54 percent of the mulch consisted of this size material.

TABLE 6

Amount of bare ground, density of mulch and vegetative cover, and percent composition of vegetation on plots of chamise brush which had been bulldozed as compared to plots which had been burned

	BULLDOZED PLOT	BURNED PLOT
	Percent	*Percent*
Bare ground	65.5	92.0
Soil surface covered by mulch	30.0	7.5
Basal density of vegetation	4.5	0.5
Foliar density of vegetation	18.0	2.0
Composition of plant cover		
Soft chess	19.5	Trace
Rose clover	9.1	0
Resident annual grasses	22.7	Trace
Forbs	5.8	25.0
Chamise (sprouts)	41.6	75.0
Wedgeleaf ceanothus	1.3	Trace

While the stand of grass and legumes in the bull-dozed plot was not ideal, it far exceeded that in the burned plot, both seeded and resident plants being more abundant. Most of the difference in density of herbaceous vegetation was attributed to extensive frost heaving of seedlings on the burned plot and relatively little on the other.

Another study also showed the importance of mulch in minimizing heaving. A 10-acre area of a 1950 wildfire burn was seeded to domestic ryegrass in the fall of that year. About an acre of this was reburned July 2, 1951, thereby destroying the plant residue. Sampling in the 1952 stands of ryegrass inside and outside of the reburned area, employing the point method, revealed the following: Total cover was twice as great on the area not reburned as on that reburned. Most of this difference was accounted for by the paucity of mulch on the latter. On a volume basis there was approximately 10 times as much mulch on the area not reburned as on that reburned. Mulch particles lying directly on the soil surface were five times as abundant. Most of the mulch consisted of stems of the 1951 ryegrass crop. Where the fire burned off the mulch, frost heaving eliminated all but a few of the ryegrass seedlings. It became evident that any plant residue or mulch left on the ground is beneficial in minimizing frost heaving.

Summary

Frost heaving of reseeded grasses and legumes on burned-over chamise brushlands in California was studied over a four-year period. The studies were in an area where the soil is often fluffy after fire and where alternate freezing and thawing is common. In many cases there was no frost heaving, but frequently it accounted for 75 percent or more mortality. Legumes were affected more severely than grasses; plants on north exposures were heaved more severely than those on south exposures. Smilo with its fine roots was heaved more severely than hardinggrass with its coarse roots. Strong and well established plants heaved less than younger and less well established plants of the same species.

Frost heaving may also account for the mortality of many brush seedlings and in some cases may affect composition of brush stands by killing more seedlings of early germinating species than those of late germinating species.

Frost heaving is effectively reduced when the soil is well covered by mulch.

The mulch moderates the extreme high and low temperatures of the soil surface. A review of literature indicates that early planting and fertilizing is helpful in developing a strong plant before the frost heaving period and is effective in lessening heaving.

Additional studies are needed on methods of seeding and fertilizing to lessen frost heaving, and on selection of species better adapted to such conditions.

Acknowledgements

The investigations were carried on cooperatively between the University of California and the California Department of Fish and Game. Work was done under Federal Aid in Wildlife Restoration Act, Pittman-Robertson Research Project California 31-R entitled "Effects of Brush Removal on Game Ranges in California."

LITERATURE CITED

Anderson, Henry W. 1947. Soil freezing and thawing as related to some vegetation, climatic, and soil variables. Jour. Forestry 45: 94–101.

Atkinson, H. B. and C. E. Bay. 1940. Some factors affecting frost penetration. Trans. Amer. Geophys. Union III: 935–951.

Barnett, R. J. 1937. Ground cover affects frost penetration. Kansas Acad. Sci. Trans. 40: 203–207.

Belotelkin, K. J. 1941. Soil freezing and forest cover. Trans. Amer. Geophys. Union I: 173–175.

McCool, M. M. and G. J. Bouyoucos. 1929. Causes and effects of soil heaving. Mich. Agr. Expt. Sta. Special Bul. 192. 11 pp.

Taber, Stephen. 1929. Frost heaving. Jour. Geol. 37: 428–461.

Taber, Stephen. 1930. The mechanics of frost heaving. Jour. Geol. 38: 303–317.

SEED TESTING

Good stands of grasses and legumes cannot be obtained from low-germinating seed, no matter how well you prepare the seedbed and sow the seed. With commercial seed, always read the label carefully. See that the seed comes from a reliable source, and that the tests for germination and purity are of recent date and show a satisfactory percentage of pure live seed. With home-grown seed, send a sample for test to a State or commercial laboratory. A germination test or live seed test is sometimes made in the home, but such tests are usually undependable because of the detailed technique required to test seeds, especially grass and legume seeds, and the difficulty of accurately interpreting the results of such tests.

Strong, viable seeds of most forage crops will retain their vitality for several years if stored in a dry, cool place where the temperature is uniform, but under average conditions, 1 to 3 years is about the limit of safety.—*From* National Farm and Garden Bureau Clipping Sheet, No. 2, 1952.