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Author(s): H. L. Shantz

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PLANT SUCCESSION ON ABANDONED ROADS IN EASTERN COLORADO.

BY H. L. SHANTZ¹.

(With twenty-three Figures in the Text.)

INTRODUCTION.

The natural vegetation at Akron, Colorado, consists largely of two grasses—the Grama grass, *Bouteloua gracilis* (*B. oligostachya*) and the Buffalo grass, *Buchloë* (*Bulbilis*) *dactyloides*. This vegetation, discussed² by the writer as the Grama-Buffalo grass association of the short-grass formation, is the principal type of the central portion of the Great Plains. If turned under by the plough and abandoned after having been cultivated for some time, the native sod will be re-established in from twenty to fifty years. The following stages may be recognized in the succession:

(1) an early weed stage consisting usually of comparatively large plants, scattered and far enough apart not to compete with each other for soil moisture;

(2) a late weed stage, a dense growth of stunted plants, the amount of growth indicating the total amount of water which was available for growth;

(3) a short-lived grass stage;

(4) a perennial stage;

(5) an early short-grass stage; and

(6) a late short-grass stage leading to the fully re-established typical short-grass sod.

The succession on abandoned roads differs from that on abandoned fields only in minor details.

FORMATION OF ROADS.

Roads were formed by vehicles driven over the short-grass sod in the same trail until the grass and sod were worn off and the soil exposed (Fig. 1). Continued use of the same trail lowered the level, partly by packing, but more largely by the gradual removal by wind of the dust particles loosened

¹ Published with the permission of the Secretary, U.S. Department of Agriculture.

² H. L. Shantz, "The Natural Vegetation as an Indicator of the Capabilities of Land for Crop Production." U.S. Department of Agriculture, Bureau of Plant Industry, Bull. No. 201, 1911.

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by the wheels of vehicles or the feet of the horses. In this way a road was considerably lowered in the course of three or four years. At this stage the road consisted of two worn trails and the central portion, which was still sodded, since few one-horse vehicles were used (Fig. 1).

When this country was first settled roads or trails led directly from one point to another, there having been no fences to interfere with travel. As fences were erected these angling roads were necessarily abandoned and new roads formed which followed the section lines.

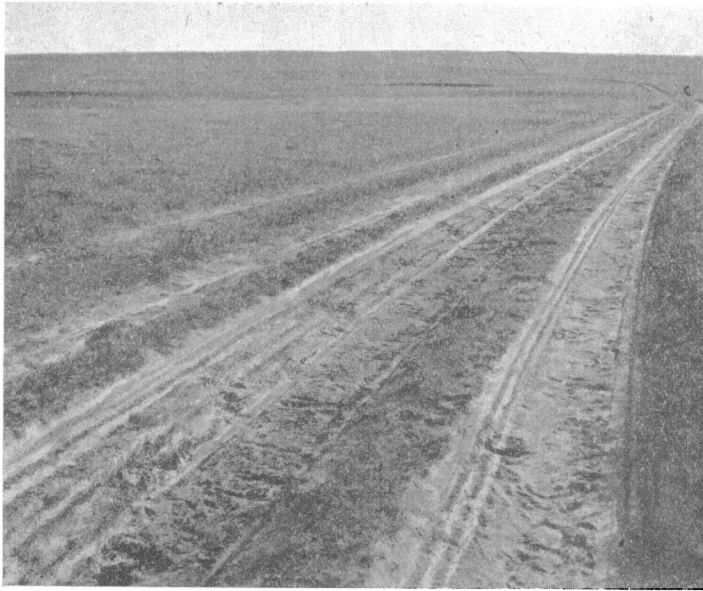


FIG. 1. Road on the High Plains in Eastern Colorado. This road is used by both single and double vehicles. The wheel tracks at the extreme right of the picture are of a double vehicle. Those next to the left are of a single vehicle, the horse travelling just to the left of the central strip of untouched grass. At the left a new road is being formed before the old one is abandoned. The vegetation in the old road has been entirely worn off except in the right centre where the native short-grass is almost undisturbed. At the left in the new road the vegetation is completely destroyed in the wheel tracks but a broad strip remains in the middle. The effect of this road on the adjacent vegetation is shown by the more luxuriant growth and the fact that the vegetation remains green longer than that of the untouched sod. Photographed Sept. 17, 1913.

Even where fences were not constructed the old roads were often abandoned. During rainy periods these roads became muddy and were less desirable for travel than the adjacent sod. In turning aside to secure a better track and thus escape the mud in the old track, one horse was pulled to the edge of the road and the other on to the sod of the middle of the road. In this way two new trails were soon formed, one in the centre and the other at the edge of the old road (Fig. 8). Roads where travel was comparatively

heavy were usually worn down more uniformly. In such cases the new road was formed at the side of the old (Fig. 2).

When once abandoned the trails were seldom used again, and new roads were seldom found on but one side of the old road. The explanation of this fact seems to be as follows: When two teams on the second road meet it is much easier for the team to turn out on the sod at the side of the road than into the old road because of the two "ruts" forming the latter. To



FIG. 2. Road on the right abandoned, road on the left still in use. The old road has been lowered from three to twelve inches and the greater portion of the vegetation destroyed. It has been abandoned one season. The original native vegetation at the edge of the road shows increased growth due to increase in available soil moisture. The vegetation in the old road consists of a few plants of *Gutierrezia sarothrae* and *Artemisia frigida* which have maintained life throughout the period when the road was in use. These are now becoming prominent features in the vegetation. The new plants which have appeared during the one year in which the road has been undisturbed are of the weed stage and are *Salsola pestifer*, *Malvastrum coccineum*, *Amaranthus graecizans*, *Polygonum aviculare*, and *Schedonardus paniculatus*. Vegetation is very sparse. Plants of later stages are present only as remnants of the undestroyed old vegetation. Photographed Sept. 17, 1913.

use the old side would necessitate driving over these two deep tracks and would occasion considerable extra jar and no little inconvenience. As a result the team driving with the old road on the right would keep its place, or at most only turn partly into the old road, while the one with the old road on the left would turn out on to the new sod. (It is customary in the United States to turn to the right.) By continuing to drive on the sod a new road was soon formed at the side of the old. When for any reason

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a team was turned aside it was always to the adjacent native sod rather than across the old ruts.

In this way a new road was formed which ran parallel to the old roads. In some places a large number were formed (Figs. 3—6). Occasionally the number of roads varies, due to the continued use of part of the old road, while at other points a new road had been formed. This condition is rarely found, except where the roads cross waterways. In such places the number



FIG. 3. A general view of a series of ten parallel roads which have been used successively since 1893. The newest road (No. 0) is at the right and was first used in 1914. The next road (No. 1) to the right of the centre of the picture was first used in 1913 and abandoned in the spring of 1915. The roadway in the centre of the picture (No. 2) was abandoned in 1914, and the vegetation which represents two seasons' growth is principally *Polygonum aviculare*. The next road (No. 3) is dominated largely by *Polygonum* but has also numerous plants of *Schedonnardus* and occasional plants of *Gutierrezia*. Road No. 5 shows a marked change in vegetation and is dominated by *Schedonnardus* with *Gutierrezia* quite abundant. The sixth road is dominated by *Schedonnardus* and *Gutierrezia*, with *Buchloë* rapidly pushing in from the sides. Photographed June 30, 1915.

of roads is usually reduced. Often the change from the old to the new road was gradual, both being used simultaneously for a time (Fig. 1) and the old road finally abandoned (Fig. 2). It often happened that after the second road had been formed new roads were formed by driving with the inner wheel in the outer of the tracks, and with the outer wheel on the sod (Fig. 9). This would come about naturally by the team not completely returning to the old road after having given half in passing another vehicle. Where so few vehicles pass that one seldom, if ever, had

to turn aside, as on some of the less frequented roads, this type of road was often developed, by turning half aside to avoid the mud of the well-beaten trails. In this way trail after trail was added until many were formed, ranging in age from the oldest on one side to the newest on the other side (see Fig. 10).

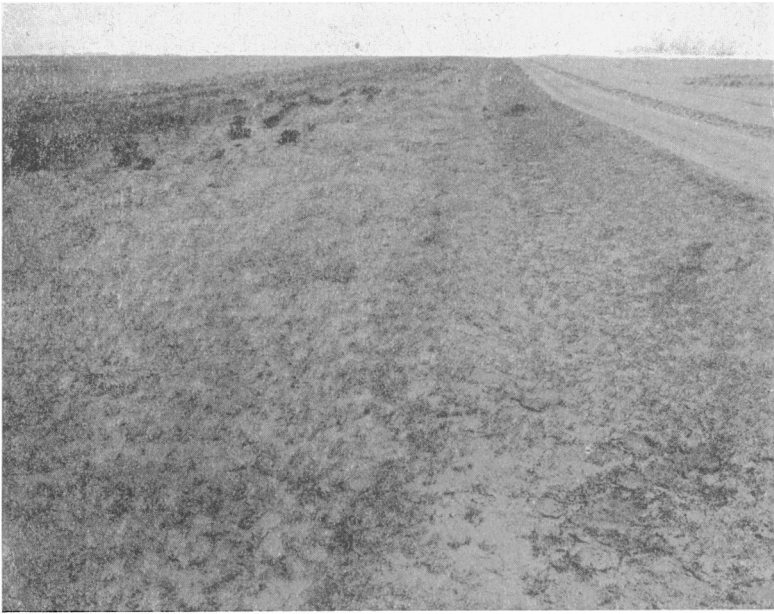


FIG. 4. A general view of the same series of parallel roads shown in Fig. 3, but photographed two years earlier. The oldest road (No. 9) is at the extreme left and the newest (No. 1) at the extreme right. Two of these roadways (Nos. 2 and 1) are now in use, the oldest of which is clearly shown in the figure. These new roads show no vegetation except an occasional plant of *Polygonum aviculare*. The third youngest road in the right foreground shows a rather dense population of *Polygonum aviculare* with occasional plants of *Salsola pestifer* and *Gutierrezia sarothrae*. The fourth road differs from the third only in the occasional occurrence of *Grindelia squarrosa* and *Schedonnardus paniculatus* and a greater number of young *Gutierrezia sarothrae* plants. The fifth road shows a marked change in vegetation. The weed stage is represented by an occasional *Grindelia squarrosa* plant and the vegetation is dominated by *Schedonnardus paniculatus* and *Gutierrezia sarothrae*. The sixth road is dominated by *Gutierrezia sarothrae* and *Schedonnardus paniculatus*. *Buchloë dactyloides* has pushed runners in at the edge for more than a foot. Grazing animals have aided in reducing the amount of growth of the weeds on roads 3 and 4. Photographed Sept. 20, 1913.

Loose cattle or horses have often formed trails approximately parallel to the roads. In such cases the oldest are usually at one side, and as the other side is approached they become successively newer (Fig. 18). These trails can easily be distinguished from the true roads by the fact that the trails are not strictly parallel (see right and left of Fig. 17 and left of Fig. 15).

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These are probably formed by several cattle travelling abreast. Those following the wheel tracks continue in a straight course while those forming the new trails parallel the wheel tracks only approximately.

The age of the vegetation on many of the roads can be told with considerable accuracy, since it is possible to ascertain when certain fences were constructed and traffic stopped.



FIG. 5. Roads 7, 8 and 9 of the series shown in Figs. 3 and 4. Road 7 at the left is dominated by *Gutierrezia sarothrae* but *Schedonnardus paniculatus* is still an important plant. Unimportant plants are *Grindelia squarrosa*, *Festuca octoflora*, *Malvastrum coccineum* and *Sporobolus cryptandrus*. An occasional plant of *Buchloë dactyloides* has become established and runners have pushed in from the side of the road. Many of the *Gutierrezia sarothrae* plants are dying. Road 8 in the right foreground is dominated at the right and left sides by *Buchloë dactyloides*. With this occurs *Grindelia squarrosa* and occasional living and many dead plants of *Gutierrezia sarothrae*. The middle portion of the road is dominated by *Gutierrezia sarothrae*, many plants of which are dying, and by many plants of *Schedonnardus paniculatus* and an occasional plant of *Buchloë dactyloides* and *Sitanion hystrix*. Road 9 shown at the extreme right, and which was first used in 1893, is almost completely resodded with *Buchloë dactyloides*, except in the very central portion which shows a vegetation of *Buchloë*, *Gutierrezia*, and an occasional *Schedonnardus*. *Gutierrezia* plants nearest the *Buchloë* are usually dying. Apparently these roads have been formed at the rate of about one in three years. The younger roads were probably formed more rapidly because of increased use during later years. In that case the age of the vegetation on these roadways is about as follows: Road 1, not abandoned; road 2, not abandoned; road 3, abandoned in 1912 (one year); road 4, in 1911 (two years); road 5, in 1908 (five years); road 6, in 1905 (eight years); road 7, in 1902 (eleven years); road 8, in 1899 (fourteen years); road 9, in 1896 (seventeen years). Photographed Sept. 20, 1913.

REVEGETATION.

The two roads shown in Fig. 1 are still in use. The vegetation has been destroyed only in the two paths, the central portion still retaining its original short-grass cover. Another strip of undisturbed short-grass lies between the new and the old road, the former showing the sod only partially destroyed in the wheel tracks. The only change in vegetation due to the road is found in the better growth of the short-grass at the edge of the road during dry years. Often it fruits along the road when it has not even flowered in the

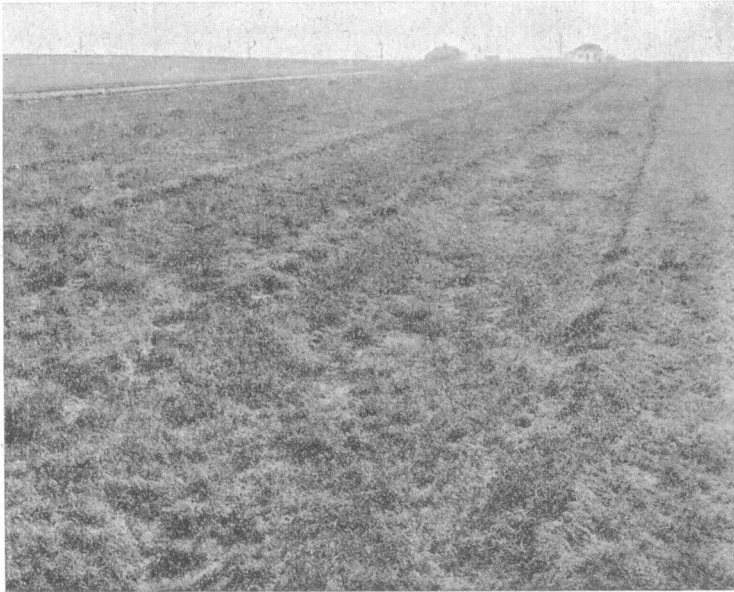


FIG. 6. Road 9 in the foreground and younger roads at left. Vegetation of road 9 shows almost pure *Buchloë* cover with remnant of *Gutierrezia* stage showing in places in the centre. Younger roads at the left show *Gutierrezia* stage. Note the narrow ridge of natural sod between the roads. Natural *Buchloë-Bouteloua* sod at the right. Photographed Sept. 20, 1913.

natural sod. A narrow green strip of grass is usually evident at the edge of the road after the natural sod is entirely dry. This is due to the reduced vegetative cover, and while the area for the absorption of rain is as great as ever the demand on soil moisture is reduced to the strip of short-grass in the centre and along the edges. Loss of water by direct evaporation from the soil is slight¹ as compared with that lost by transpiration from the

¹ This is true whether the surface of the road be covered with a dust mulch or be bare hard surface.

See **W. W. Burr** (1914), "Storage and Use of Soil Moisture." Research Bulletin No. 5 of the Agricultural Experiment Station of Nebraska, p. 61. Also, **Romistov, V. G.** (1913), "The Nature of Drought According to the Evidence of the Odessa Experiment Field." M.L. and A. Department of Agriculture, Odessa, 1913, p. 17.

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plants and therefore conditions for soil moisture conservation are more favourable in the roads than in the undisturbed sod.

A somewhat later stage is shown in Fig. 2. The old road has been worn almost completely bare and abandoned since the previous summer. A few perennials, chiefly *Gutierrezia sarothrae* and an occasional *Artemisia frigida*, which were not entirely killed by the trampling are now making a good



FIG. 7. Three roads used before road 9 of Figs. 5 and 6 was formed. A fence constructed across the roads shown here caused the formation of road 9 in 1893. The road at the right was formed in 1886; seven years later in 1893 all were abandoned. Road 10 at the left of the figure was only slightly used. Roads 11 and 12 were almost equally travelled when abandoned. Road 12 was apparently abandoned some years before roads 10 and 11 and shows a somewhat older vegetation. It seems safe to assume that road 12 was abandoned about three years before 10 and 11. Hence 10 and 11 were abandoned in 1893, or twenty years, and road 12 about 1889, or twenty-three years. Road 10, which is the youngest of these three (20 years), is almost completely resodded by *Bouteloua gracilis* and *Buchloë dactyloides*, due to the incomplete destruction of these plants before the road was abandoned. Road 11 (20 years) shows almost pure sod of *Buchloë* and *Bouteloua* but also many living and dead plants of *Gutierrezia sarothrae*. Road 12 (23 years) shows practically a pure *Buchloë-Bouteloua* sod with a few living and dead *Gutierrezia* plants. Photographed Sept. 20, 1913.

growth. The following plants have already begun to colonize the old road: *Salsola pestifer*, *Amaranthus graecizans*, *Polygonum aviculare*, *Malvastrum coccineum*, *Schedonnardus paniculatus*. With the exception of the last two species these plants represent the weed or first stage in revegetation. At the time the photograph was taken no available soil moisture was found in the native vegetation at the side of this road. In the new trail less than

two per cent. of water was available in each of the surface three feet. During the early season the vegetation which had at that time not been destroyed removed much of the soil moisture. The abandoned road showed from six to nine per cent. of water available in each of the surface three one-foot layers.

In Fig. 8 is shown a road abandoned but one season. The revegetation is very slight, with only an occasional plant of the ruderal stage, such as *Grindelia squarrosa*, *Polygonum aviculare* and *Schedonnardus paniculatus*.



FIG. 8. Road abandoned one season. The central track used principally by a single horse shows incomplete destruction of short-grass sod. The two main travelled tracks are practically bare except for an occasional plant of *Polygonum aviculare*, *Schedonnardus paniculatus*, and *Grindelia squarrosa*. The trail at the left is the result of driving a single rig with the horse in the left main track. If this road had been used for a period of years the new trails would undoubtedly have been formed at the left. Photographed Sept. 20, 1913.

The old road in Fig. 9 has been abandoned for three years. The stage of revegetation is what may be called a late weed stage. While weeds do not play as important a part on abandoned roads as on abandoned tilled land, still the first plants to enter these roads are often the same as those of abandoned fields. Roads are more likely to be occupied by plants naturally occurring in the short-grass but which only now and then spring into prominence. In this figure *Grindelia squarrosa* is a prominent plant, although this prominence is only temporary. Had the photograph been taken one year before or one year later this plant would not have been as

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prominent in the succession. About the only other plants are *Polygonum aviculare*, a representative of the weed stage, *Schedonnardus paniculatus*, a representative of the short-lived grass stage, and an occasional plant of *Gutierrezia sarothrae*. At the edges *Buchloë dactyloides* is slowly sending out runners.

In Fig. 11 an old road is shown which has been abandoned nine years. At this point conditions are unusually favourable for revegetation. The central part of the road is in the *Schedonnardus* stage. *Monroa squarrosa* is also associated with *Schedonnardus*. In the background *Gutierrezia sarothrae*



FIG. 9. The old road (three tracks) at the right was abandoned in the spring of 1911. The new road at the left has been used three seasons by teams and automobiles. The vegetation in the old road consists of *Polygonum aviculare*, *Schedonnardus paniculatus*, *Gutierrezia sarothrae* and *Grindelia squarrosa*. Runners of *Buchloë* have almost crossed the narrow tracks in places. Early weed stage. Photographed Sept. 20, 1913.

and *Aristida longiseta* are present in the centre of the road. The sides are dominated by *Buchloë* which forms a rather dense sod area $1\frac{1}{2}$ feet wide on either side. Here in the foreground the vegetation is passing directly to the *Buchloë* stage, *Gutierrezia* having entirely disappeared from the succession.

A road formed in 1890 was abandoned in 1900 due to the construction of a fence directly across its path. Three different sections of this road are presented in Figs. 12, 13 and 14, to emphasize the fact that the rate of development of the succession is not uniform. In the native undisturbed sod, areas

of vegetation occur which belong to an earlier stage in the natural succession. Succession on old roads is much more rapid in some places than in others. Usually where the road passes through a less thoroughly sodded area the revegetation is slow, but where the native sod is a pure even short-grass cover the succession is more rapid.

In Fig. 12 the vegetation is 13 years old and in the *Gutierrezia* stage. There are also a few remnants of the *Schedonnardus* stage.

In Fig. 13 the vegetation, although of the same age, is in the late



FIG. 10. A series of thirteen parallel tracks (about eight roads) east of Otis, Colorado. The newest roads are now used largely by automobiles. The first five tracks are nearly bare. The vegetation of track 6 is largely young *Schedonnardus* and the annuals, *Plantago purshii* and *Leptilon canadense*; of tracks 7 to 9, mostly *Schedonnardus*; and 10 to 13, mostly *Buchloë*. The ridges between the trails are covered with a typical short-grass. The tracks are filled with the fruiting stalks of *Schedonnardus* which have been blown in from the adjacent short-grass sod. This will explain rapid seeding of new trails to *Schedonnardus*. Photographed Aug. 10, 1915.

Gutierrezia stage or early *Buchloë* stage. In Fig. 14 the succession has in the same period of time reached the *Buchloë* stage, although the *Gutierrezia* stage is still found in the right track.

Vegetation sixteen years old is shown on the trails and roads illustrated in Fig. 15, with the exception of the trail at the extreme right which is still used occasionally by cattle. The vegetation of the trails and roads is in the *Buchloë* stage.

A still older road on which the vegetation has returned to the *Bouteloua-Buchloë* stage in 21 years is shown in Fig. 16. This road was used only

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one year and then abandoned. The complete revegetation was doubtless favoured by the incomplete destruction of the original sod.

In Fig. 18 is shown a series of 23 trails formed by cattle and vehicles, the oldest of which is shown at the left front of the photograph. Successively newer trails occur at the right. Some of the trails were worn much deeper than others. The accompanying diagram (Fig. 19) shows the dominant vegetation of each of these trails. Trails 1 and 2 are still in use and trail 1 shows no vegetation. Trail 3 is used occasionally. Trails 2 to 8



FIG. 11. Road in use in 1897 and abandoned about 1904. Vegetation nine years old when photographed. Central portion dominated by *Munroa squarrosa* and *Schedonnardus paniculatus*, while both sides are dominated by *Buchloë dactyloides*, the runners of which have moved in from the sides. *Gutierrezia sarothrae* and *Aristida longiseta* have established themselves in the central part of the road in the background. Moisture conditions at this point were favourable and *Buchloë* showed unusual activity in advancing on to the road. Road at right consisted of but a single wagon track. Photographed Sept. 17, 1914.

are partially covered with *Polygonum*; 9 and 10 with *Polygonum* and *Schedonnardus*; 11 to 13 with *Gutierrezia*, *Schedonnardus* and *Buchloë*; 15, 17 and 19 with *Gutierrezia*, *Buchloë*, and *Schedonnardus*; 14, 16 and 18 with *Buchloë*, *Gutierrezia* and *Schedonnardus*; 20 with *Buchloë* and *Gutierrezia*, and 21 to 23 with *Buchloë* and *Bouteloua*. The revegetation of trails, which seldom exceed $1\frac{1}{2}$ feet in breadth, is more rapid than on roads 6 feet in breadth. The same stages are evident, however, in the succession. Revegetation of trails by *Buchloë* is accomplished largely by the runners. On the roads reseeding becomes an important factor.

A bare cattle trail with no remnant of vegetation of any kind is shown at the left of Fig. 18. Fig. 20 illustrates a trail abandoned about five years and now in the *Gutierrezia* stage, with *Schedonnardus* a remnant of the earlier stage and *Buchloë* becoming established slowly. Fig. 21 shows an old trail in the final stage of revegetation. The trail leads from the lower right foreground of the photograph back through the right central portion. It is distinguished with difficulty since there is no change of vegetation type and only the slight depression to mark its course.



FIG. 12. Road formed about 1890 and abandoned in 1900. Vegetation thirteen years old. This road shows the *Gutierrezia* stage with the *Schedonnardus* stage represented by an occasional plant. Photographed Sept. 15, 1913.

The method of road formation and the different stages of succession are well illustrated in a single series of roads leading into the city of Akron, Colorado, from the east.

The first road was formed in 1886. During the next seven years two new tracks were formed on the south side of this road (Figs. 3, 4, 7). In 1893 a fence was constructed which shut off the road and forced travel to pass about 75 metres to the south. Here a new road was formed in 1893. Additional roads were formed and in 1913 nine roads paralleled each other at this place. Since 1913 one new track has been formed and the two roads in use in 1913 abandoned. There are now (1915) thirteen roads in all, the oldest having been formed in 1886 and the newest in 1914.

Revegetation on these roads is clearly shown in the bisect and transect

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in Fig. 23. Roads of various ages are here shown in one location and the succession on these abandoned roads is typical for this part of the Great Plains. The transect was made in 1913 and consequently does not apply to the vegetation shown in Fig. 3, which was taken two years later.

The vegetation at this point is typical short-grass. In road No. 1 the vegetation has been worn off (Figs. 4, 17), only the roots of the short-grasses remaining. An occasional trampled plant of *Polygonum aviculare* constitutes the only vegetation. Between roads 1 and 2 there is a narrow strip of undisturbed short-grass. Road 2 was abandoned early in the summer of 1913. Vegetation is almost as sparse as in road 1 and consists of the

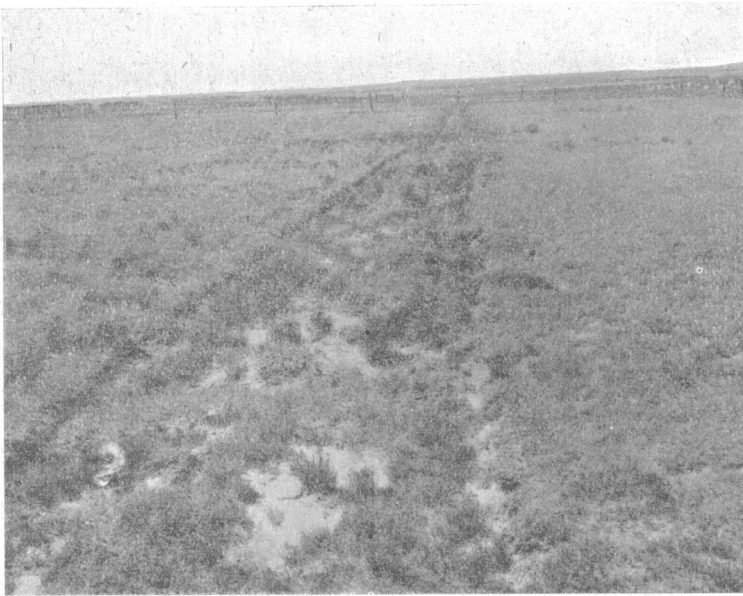


FIG. 13. Same road as shown in Fig. 9. Although of the same age the vegetation here represents a somewhat later stage—a late *Gutierrezia* and early *Buchlöë* stage. Photographed Sept. 15, 1913.

same species. Road 3 has been abandoned about one year and is covered with a fairly even growth of *Polygonum aviculare*. In this road an occasional plant of *Salsola pestifer* or *Gutierrezia sarothrae* is found. Road 4, abandoned about two years, is still in the weed stage and is dominated by *Polygonum aviculare*, with occasional plants of *Grindelia*, *Schedonnardus* and *Gutierrezia*. Between roads 4 and 5 the short-grass is left only in occasional mats. Road 5, abandoned about five years, is dominated by *Schedonnardus paniculatus*. With this are found many plants of *Gutierrezia*. No short-grass area separates road 5 from road 6. In the latter road, which has been abandoned about eight years, *Gutierrezia* is dominant, although *Schedonnardus* is still a

prominent plant. *Buchloë* is pushing in rapidly from the sodded area between road 6 and road 7. The vegetation of road 7 (Fig. 5) is approximately eleven years old. *Gutierrezia* is dominant, although *Schedonnardus* has not given way entirely, and both *Buchloë* and *Bouteloua* are entering.

Gutierrezia is dying out rapidly in road 8 (Fig. 5) which has been abandoned about fourteen years. *Buchloë* has pushed far into the road from the sod areas at the sides and has also established mats by reseeding. In road 9



FIG. 14. Same road as shown in Figs. 11, 13. Here *Buchloë* is almost entirely established and a considerable amount of *Bouteloua* is also present at the left centre. At the right the *Gutierrezia* stage is still prominent. These three photographs illustrate the differences in stages which may be encountered on roads abandoned for the same number of years. Conditions for vegetation are not equally favourable. Just as in the native sod many places show a more primitive vegetation type, so in these roads such areas are usually clearly reflected in this secondary succession. In these three figures the stages of vegetation are youngest in the areas where the natural cover is most primitive in character and most advanced where the natural vegetation is of the purest type of Grama-Buffalo grass.

(Fig. 6), in which the vegetation is approximately seventeen years old, *Buchloë* has replaced *Gutierrezia*, except in an interrupted narrow strip near the centre of the road. Dead plants of *Gutierrezia* persist in the *Buchloë* sod.

In road 10 (Fig. 7) the vegetation is about twenty years old. Here *Buchloë* is dominant and most of the *Gutierrezia* plants are dead. Roads 10, 11 and 12 differ only slightly in vegetation. *Bouteloua* is a more important plant in road 12, which has been abandoned about twenty-three years, than in the later roads.

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Briefly, roads 2 and 3 belong to the (1) early weed stage, road 4 to the (2) late weed stage, road 5 to the (3) *Schedonnardus* stage, roads 6, 7 and 8 to the (4) *Gutierrezia* stage, and roads 9--12 to the (5) *Buchloë* stage.

The season 1915 was an unusually wet one and notes made on this series of roads on June 30 may be summarised as follows.

Native sod:—*Bouteloua gracilis* and *Buchloë dactyloides*, with a few scattered plants of *Plantago purshii*, *Festuca octoflora*, *Malvastrum coccineum*, *Grindelia squarrosa*, *Gutierrezia sarothrae* and *Erysimum asperum*.

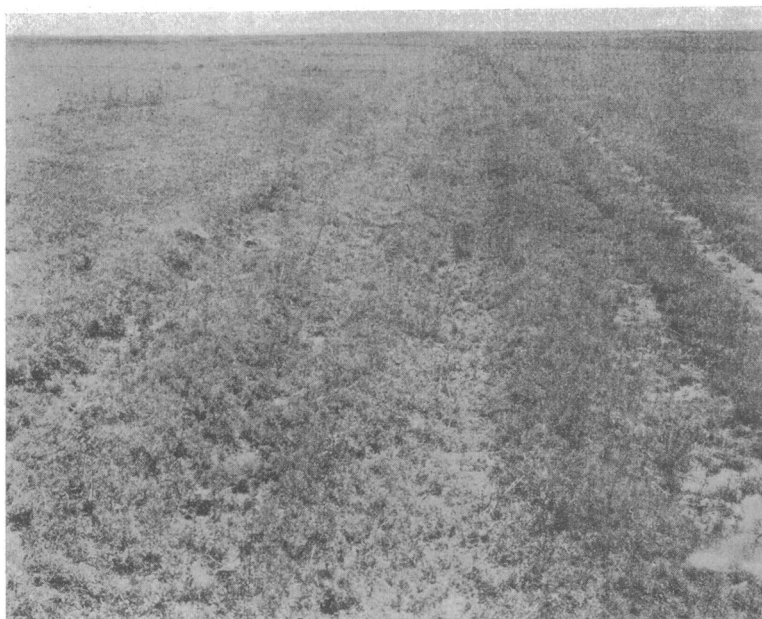


FIG. 15. Roads and trails formed in 1898 and soon abandoned. Vegetation about sixteen years old. All trails, except that at the extreme right, show the *Buchloë* stage. This trail, which has been used by cattle rather recently, is in the ruderal stage. The five tracks from the right to the left are the roads. Two trails are shown at the left.

Road 9:—pure *Buchloë dactyloides* at the sides; centre shows *Sitanion hystrix*, *Gutierrezia sarothrae*, *Grindelia squarrosa*, *Festuca octoflora*, *Plantago purshii*, *Malvastrum coccineum* and *Erigeron canus*.

Road 8:—rather open vegetation of *Buchloë dactyloides*, with scattered plants of *Gutierrezia sarothrae*, *Schedonnardus paniculatus*, *Grindelia squarrosa*, *Sitanion hystrix*, *Festuca octoflora*, *Plantago purshii*, *Erysimum asperum*, *Lepidium ramosissimum*, *Malvastrum coccineum*, *Hedeoma hispida* and *Psoralea tenuiflora*.

Road 7:—scattered growth of *Gutierrezia sarothrae* and *Schedonnardus paniculatus*, and a few plants of each of the species listed under road 8.

Road 6:—very open—scattered plants of *Gutierrezia sarothrae* and

Schedonnardus paniculatus and an occasional plant of *Grindelia squarrosa*, *Sitanion hystrix*, *Hedeoma hispida*, *Malvastrum coccineum* and *Sporobolus cryptandrus*.

Road 5:—more open than 6 and dominated by *Schedonnardus paniculatus*, with a few plants of *Sitanion hystrix*, *Gutierrezia sarothrae*, *Grindelia squarrosa*, *Lepidium ramosissimum*, *Plantago purshii*, *Verbena bracteosa* and *Buchloë dactyloides*.

Road 4:—largely *Polygonum aviculare*, with a few plants of *Schedonnardus paniculatus*, *Gutierrezia sarothrae*, *Festuca octoflora* and *Plantago purshii*.



FIG. 16. Road formed in 1891 and abandoned in 1892. Vegetation about twenty-one years old, and can be distinguished from the undisturbed sod only by lower level of the soil surface. Photographed Sept. 20, 1913.

Road 3:—*Polygonum aviculare*, with a small number of plants of *Schedonnardus paniculatus*, *Festuca octoflora*, *Sitanion hystrix* and *Gutierrezia sarothrae*.

Road 2:—a pure dense cover of *Polygonum aviculare*; this plant is much darker in colour in this road than in road 3, due to the better moisture supply; crude chlorophyll extract shows the chlorophyll content to be about three times as great as in road 3.

Road 1:—a few scattered plants of *Polygonum aviculare*.

Road 0:—bare except for an occasional plant of short-grass in the central portion of the road.

A comparison with the notes taken in 1913 shows very little change in the

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older roads but a more pronounced change in the younger roads. The change of vegetation in two years is slight. Road 1 has passed into the early weed stage, roads 2 and 3 into the late weed stage, while road 4 has almost passed from the weed stage to the *Schedonnardus* stage.

GENERAL DISCUSSION.

Although some variation is found in the revegetation of different roads in this region the following stages may be clearly distinguished.



FIG. 17. Roads and trails. The third and fifth tracks from the left represent the oldest road. These tracks are now in the *Buchloë* stage. The second and fourth tracks are younger and show about half as much *Buchloë* as the oldest road. The first track at the left is a new cow trail and shows no vegetation. Another cow trail at the extreme right is in the *Buchloë* stage. The trails are only approximately parallel to the roads. Photographed Sept. 17, 1913.

The first, or early weed stage, formed on roads abandoned from one to three years. Plants are scattered, and in dry years are small. In wet years this stage passes rapidly over into the second stage. The species which constitute this stage are chiefly the following weeds:—*Polygonum aviculare*, *Salsola pestifer*, *Verbena bracteosa*. With these occur the following annuals or biennials which occur regularly in the short-grass sod:—*Plantago purshii*, *Festuca octoflora*, *Grindelia squarrosa*. A great deal of variation is shown, and any of the following may also occur:—*Dysodia papposa*, *Amaranthus blitoides*, *Amaranthus graecizans*, *Chenopodium incanum*.

The second, or late weed stage, on roads abandoned from two to five years, is one in which the plants which have entered in the first stage reach their greatest development and begin to disappear. In the latter part of this stage *Schedonnardus paniculatus*, *Gutierrezia sarothrae* and *Malvastrum coccineum* enter.

The third, or *Schedonnardus paniculatus* stage, extends from four to eight years after abandonment. *Schedonnardus* replaces the weeds which preceded and becomes dominant. *Gutierrezia sarothrae* gradually enters and becomes increasingly more important.



FIG. 18. A series of twenty-three trails and roads, the oldest at the left and the youngest at the right. Beginning at the right, trails 1 and 2 are still in use. Trail 3 is also used occasionally. Trails 2 to 8 are mostly bare but partly covered with *Polygonum*; trails 9 and 10 with *Polygonum* and *Schedonnardus*; 11, 12, and 13 with *Gutierrezia*, *Schedonnardus* and *Buchloë*; 15, 17 and 19 with *Gutierrezia*, *Buchloë* and *Schedonnardus*; 14, 16 and 18 with *Buchloë*, *Gutierrezia* and *Schedonnardus*; 20 with *Buchloë* and *Gutierrezia*, and 21 to 23 with *Buchloë* and *Bouteloua*. Trails 14 to 23 show dead *Gutierrezia* plants. These trails have been formed by both vehicles and cattle. Photographed Sept. 17, 1913.

The fourth, or *Gutierrezia sarothrae* stage, occurs on roads abandoned from seven to fourteen years. This plant gradually replaces *Schedonnardus* and is in turn replaced by *Buchloë*.

The fifth, or *Buchloë dactyloides* stage, occurs on roads abandoned from thirteen to twenty-three years. This plant gradually kills out most of the *Gutierrezia* but is never entirely replaced by any other. *Bouteloua* gradually enters and the typical short-grass sod formed in the next stage.

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The sixth, or *Bouteloua gracilis*—*Buchloë dactyloides* stage, extends from twenty to fifty years after abandonment. At the end of this time the composition of the vegetation cannot be distinguished from the undisturbed short-grass. Under unfavourable conditions the pure short-grass sod is never developed.

ORDER OF IMPORTANCE.

	1	2	3	4	5
1*	O				
2*	O	O	P		
3†	O	O	O	P	
4	O	P			
5	O	P			
6	O	P			
7	O	P			
8	O	P			
9	O	P	S		
10	O	P	B	S	
11	O	O	G	S	B
12	O	S	G	B	
13	O	G	S	B	
14	O	B	G	S	
15	O	G	B	S	
16	B	O	S	G	
17	G	B	O	S	
18	B	G	S		
19	G	B	S		
20	B	BG	G		
21	B	BG			
22	B	BG			
23	B	BG			

* STILL IN USE.

† STILL USED OCCASIONALLY.

O = BARE GROUND
 P = POLYGONUM AVICULARE
 S = SCHEDONNARDUS PANICULATUS
 G = GUTIERREZIA SAROTHRAE
 B = BUCHLOË DACTYLOIDES
 BG = BOUTELOUA GRACILIS

FIG. 19. Diagram showing the dominant vegetation of each of the 23 trails shown in Fig. 18.

There are certain variations in the successions outlined above. In eastern Colorado *Sitanion hystrix* or *Munroa squarrosa* may occasionally

take the place of *Schedonnardus paniculatus*. Nearer the mountains *Dysodia papposa*¹ often initiates the weed stage. Under more favourable conditions, i.e. farther east, where the rainfall is greater, or on more sandy soil, *Aristida longiseta* will take the place of the *Gutierrezia* stage. Nearer the mountains in Colorado, in a vegetation dominated by *Bouteloua gracilis*, *Stipa vaseyi* takes the place of *Gutierrezia* and the vegetation passes directly into the *Bouteloua* stage from the *Stipa* stage, or through an intermediate stage of *Muehlenbergia gracillima*¹. Farther north *Artemisia frigida* takes the place

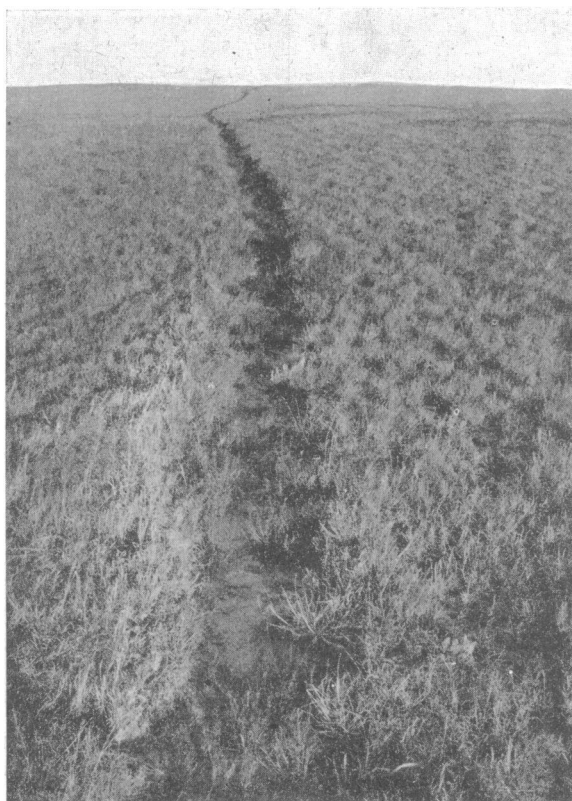


FIG. 20. Cattle trail abandoned about five years. Vegetation is in *Gutierrezia* stage. Some *Schedonnardus* still present and *Buchloë* entering. Photographed Sept. 20, 1913.

of *Gutierrezia* and is replaced by *Bouteloua gracilis*. In this case the fifth stage in the succession outlined below is omitted. In wheat grass (*Agropyron smithii*) areas this plant enters as the first perennial and is followed by *Buchloë* and *Bouteloua*.

¹ Shantz, H. L., "A Study of the Vegetation of the Mesa Region East of Pike's Peak. I. The *Bouteloua* Formation. II. Development of the Formation." *Botanical Gazette*, **42**, 179—207, 1906, pp. 190—195.

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The succession as outlined here applies with almost no modification south to the "pan-handle" of Texas, and is typical, with minor modifications, for succession anywhere in the *Bouteloua*—*Buchloë* or *Bouteloua* associations from Texas to Montana. As modified by the discussion above the following is a general statement of the species which dominate the different stages:

(1) **Early weed stage:** scattered plants of:—*Polygonum aviculare*, or *Verbena bracteosa*, or *Salsola pestifer*, or *Dysodia papposa*, or *Amaranthus blitoides*.

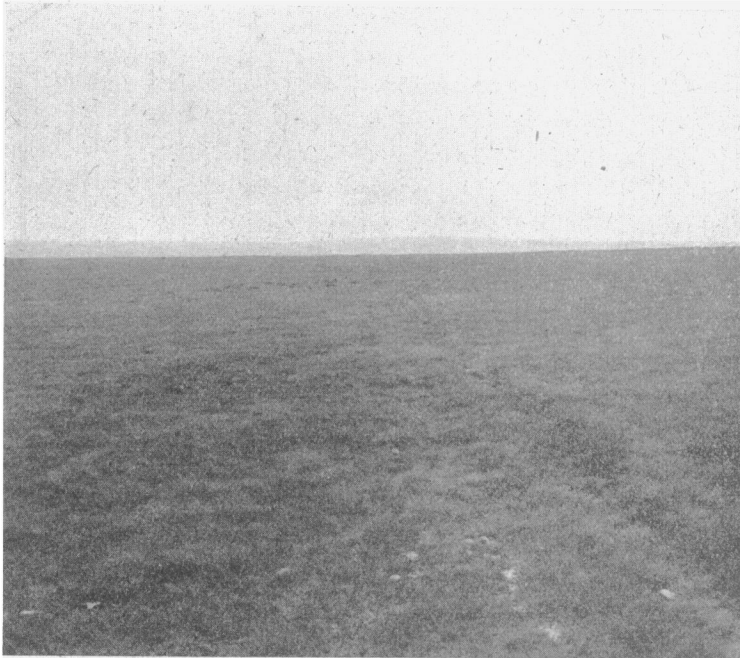


FIG. 21. Old trail showing complete revegetation. Photographed Aug. 27, 1907, near Burlington, Colorado. (From Plate I, Fig. 1, Bulletin 201, Bureau of Plant Industry.)

(2) **Late weed stage:** dense growth of plants of stage (1).

(3) **Short-lived grass stage:** *Schedonnardus paniculatus*, or *Munroa squarrosa*, or *Sitanion hystrix*.

(4) **Perennial stage:** *Gutierrezia sarothrae*, or *Aristida longiseta*, or *Stipa vaseyi*, or *Artemisia frigida*.

(5) **Early short-grass stage:** *Buchloë dactyloides*, or *Muehlenbergia gracillima*.

(6) **Late short-grass stage:** *Bouteloua gracilis*—*Buchloë dactyloides*, or *Bouteloua gracilis*.

The stages of succession here outlined as they occur on abandoned roads do not differ essentially from those on fields which have been abandoned¹.

THE CAUSES OF THE SUCCESSIONS.

The successions are initiated by the destruction of the plant cover. Where a road is abandoned, the soil is generally well supplied with water and conditions are unusually favourable for plant growth. Any of the plants of the later stages of the succession would grow here, but those which are best adapted rapidly



FIG. 22. A graded roadway with road formed at the right of the centre. The grading was done two years before. The principal plants are *Polygonum aviculare*, *Salsola pestifer*, *Gaura coccinea*, *Malvastrum coccineum*, *Amaranthus retroflexus*, *Amaranthus blitoides*, *Chenopodium leptophyllum*, *Chenopodium album*, *Chenopodium incanum*, *Leptilon canadense*, *Buchloë dactyloides* and *Grindelia squarrosa*. The vegetation is much more mixed than on ungraded roads, and more nearly like that on abandoned tilled land. Photographed Aug. 23, 1915.

to seed the new area enter first. It is natural, therefore, that the first stage should be a weed stage. The density of the stand in the early weed stage is a measure of the success with which plants have seeded this area and germinated. In the late weed stage the density of stand and the amount of

¹ Shantz, H. L., "Natural Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains area." U.S. Department of Agriculture, Bureau of Plant Industry, Bulletin 201, pp. 40—42.

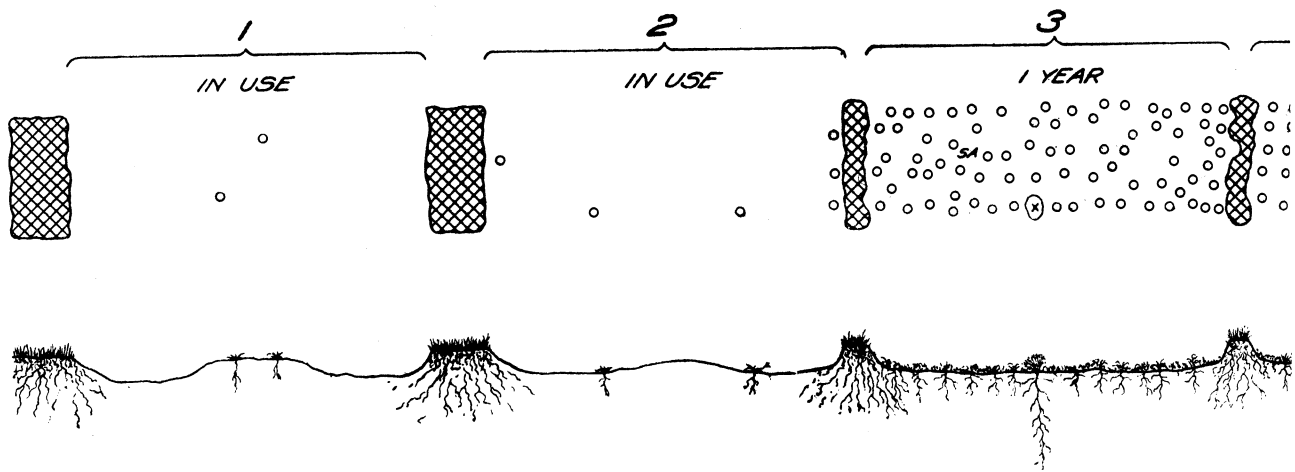
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growth is an expression of the amount of water available for growth. In this second weed stage the area is often seeded so densely that the individual plant cannot develop, but remains small and stunted.

The next stage is a temporary grass stage usually formed by *Schedonnardus*. A glance at Fig. 9, will show how well this plant is adapted to reseed these abandoned roads. The depressions are often filled with the wiry panicles of this plant which is present in small numbers in the natural short-grass sod. The panicles are blown by the wind and lodge among the weeds on the old roads. Here when once established *Schedonnardus* shuts out the annuals, since a surface feeding perennial can usually exhaust the moisture supply in the surface soil before the young seedlings of the weeds can become established.

Schedonnardus, which is a short-lived perennial, does not replace the few plants of *Gutierrezia* which have already entered and does not prevent new plants from becoming established. *Gutierrezia* can utilize soil moisture of the deeper layers as well as the surface layers and gradually replaces the *Schedonnardus* which, although not an annual, is a comparatively short-lived grass.

The long-lived surface feeding *Buchloë* gradually replaces the *Gutierrezia*. By consuming the water as it enters the surface soil, *Buchloë* effectively cuts off the moisture supply to the deeper soil layers and the deep root system of *Gutierrezia* is no longer effective in supplying water to the plant. Much of the *Gutierrezia* gradually dies out and remains as dead bushes for some time. The roots can be detected in the soil under the *Buchloë* sod after the plants have disappeared from the surface. *Bouteloua* reseeds very slowly and only after a number of years has it become as dominant as the *Buchloë*.



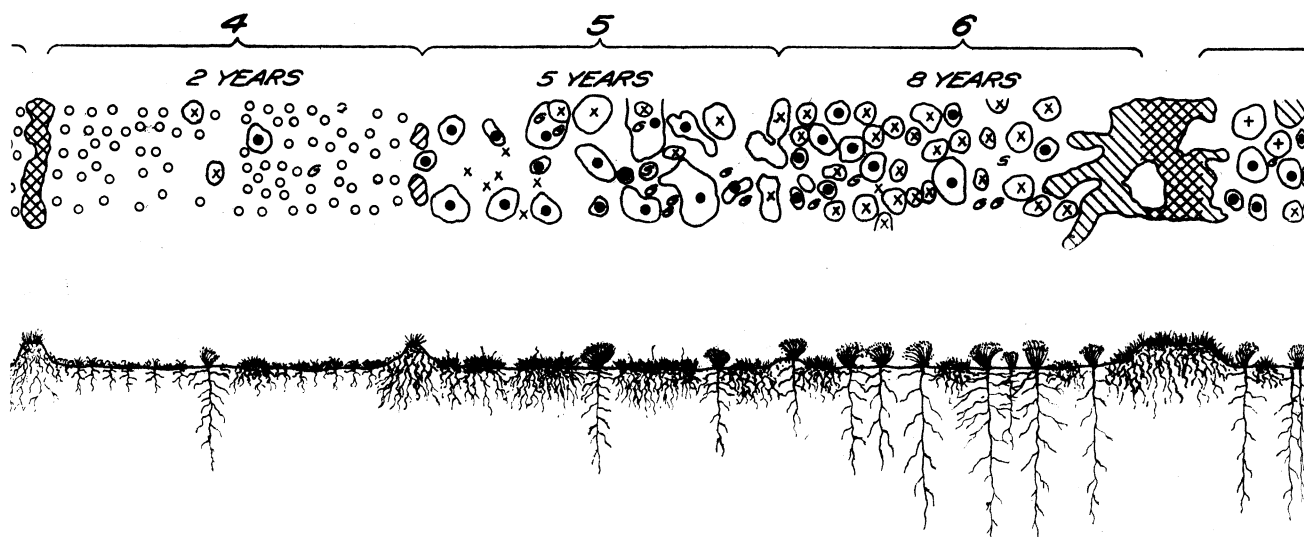
BUCHLOË DACTYLOIDES



BOUTELOUA GRACILIS

O = *POLYGONUM*

1. New road—vegetati short-grass and an occasio 1 and 2.)
2. Still in use, track b of road. (Typical short-gr
3. Well covered with of young *Gutierrezia saroth*
4. Largely *Polygonum culatus* and *Grindelia squa*



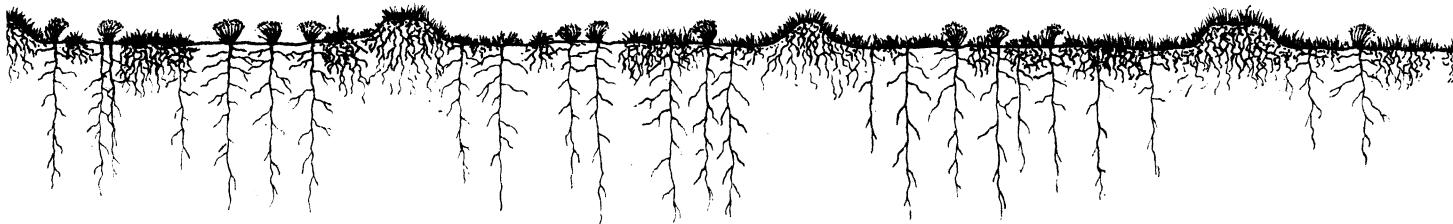
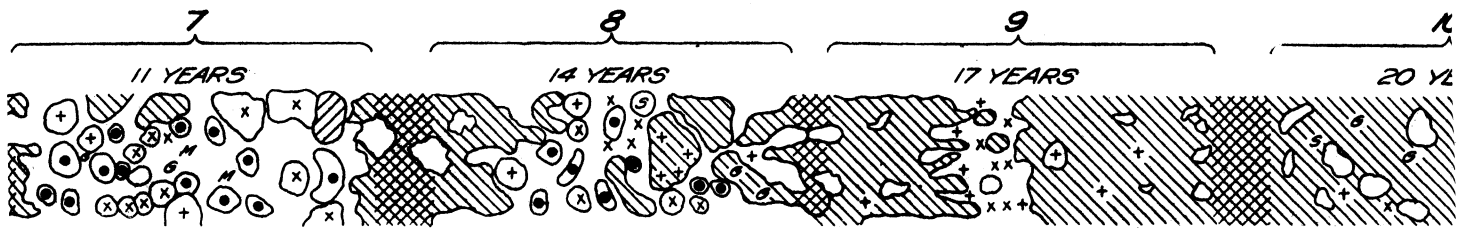
Polygonum aviculare

x = *Gutierrezia sarothrae*

s = *Sitanion hystrix*

FIG. 23. A combined bisect and transect of a series of abandoned roads shown in Figs 3—8. The vegetation at sides typical short-grass. In centre grass roots of trampled occasional plant of *Polygonum aviculare*. (Typical short-grass between track bare. A few plants of *Polygonum aviculare*, especially in centre short-grass between 2 and 3.)
 4. Covered with *Polygonum aviculare* and a few plants of *Salsola pestifer* and *Gutierrezia sarothrae* (short-grass between 3 and 4). Abandoned about 1 year.
 5. Covered with *Polygonum aviculare* and some *Gutierrezia sarothrae*, *Schedonnardus paniculatus* and some *Grindelia squarrosa*. Abandoned about 2 years.

6. Largely *Schedonnardus paniculatus* and you an occasional plant of *Grindelia squarrosa*. Abandoned about 5 years.
 7. *Gutierrezia sarothrae* and *Schedonnardus paniculatus* and occasional plants *dactyloides*, *Grindelia squarrosa*, *Malvastrum coccineum*. Abandoned about 8 years.
 8. The right and left portions of this road are largely *Gutierrezia sarothrae* and *Schedonnardus paniculatus*.



ON HYSTRIX

SA = SALSOLA PESTIFER

● = SCHEDONNARDUS PANICULATUS

3—8. The plants of the bisect may be identified by reference to the transect. Mapped Sept. 17, 1913.

tus and young plants of *Gutierrezia sarothrae*, with *sa*. Abandoned about 5 years.

nardus paniculatus and occasional plants of *Sitanion oë* has penetrated from the side adjacent to road 7.

ional plants of *Schedonnardus paniculatus*, *Buchloë trum coccineum*, and *Sporobolus cryptandrus*. Road

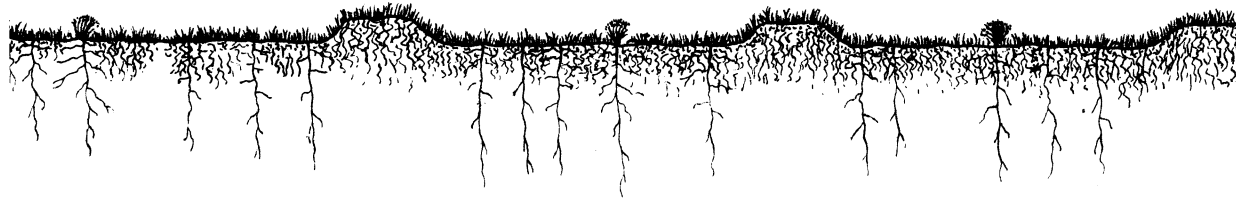
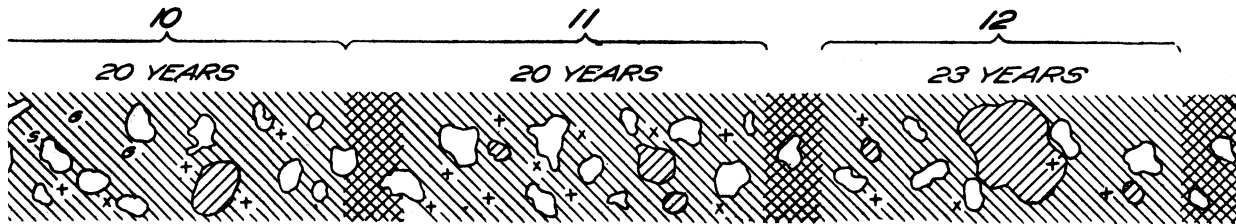
is road are largely *Buchloë*; and the central portion, *paniculatus*. Road abandoned about 14 years.

9. The right and left sides of this road are largely *Buchloë* and the central portion largely *Gutierrezia sarothrae*, much of which is dead. The dead plants are indicated by root portion only, since the tops are often broken and blown away. Road formed 1 and abandoned about 17 years.

10. Short-grass with dying or dead *Gutierrezia sarothrae* (road abandoned 18 Vegetation 20 years old.

11. Short-grass with dying, dead and living *Gutierrezia sarothrae* (road abandoned 1893). Vegetation 20 years old.

12. Short-grass with dying or dead *Gutierrezia sarothrae*. Road formed in 1886 abandoned about 1891 Vegetation 23 years old.



LATUS + = DEAD *GUTIERREZIA* *G* = *GRINDELIA SQUARROSA*

the central portion is
 s are indicated by the
 Road formed 1893
 and abandoned 1893).
 rae (road abandoned
 formed in 1886 and