United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Research Station**

General Technical
Report PSW-123

VEGETATION
MANAGEMENT
Research and Development
Program

Mulches Aid in Regenerating California and Oregon Forests: Past, Present, and Future

Philip M. McDonald Ole T. Helgerson

McDonald, Philip M.; Helgerson, Ole T. 1990. **Mulches aid in regenerating California and Oregon forests: past, present, and future.** Gen. Tech. Rep. PSW-123. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 19 p.

The use of mulches as a reforestation tool in Oregon and California began primarily in the late 1950's. Many types of mulches were tried including sheets of plastic, newspaper, and plywood; various thicknesses of bark, sawdust, sand, and straw; sprayed-on petroleum resin; and even large plastic buckets. Most proved to be ineffective, costly or both. Early trials tended to use small, short-lived materials that aided conifer seedling survival, but not growth. Compared to other weed-control techniques available at the time, mulches were rather expensive. Current trends are to apply longer-lived, somewhat larger mulches of mostly sheet materials made of reinforced paper, polyester, or polypropylene. When the various costs of mulching (material, installation, and maintenance) are totalled, the overall cost of the technique continues to be high. Recently, new mulch materials of polyester, polypropylene, or combinations of both have allowed silviculturists to consider large, durable mulches (10 by 10 feet or 3 by 3 m) for enhancement of growth (not just survival), and to control plants with stiffer stems.

Retrieval Terms: mulching, cost, effectiveness, conifer seedlings, survival, growth

The Authors:

PHILIP M. MCDONALD is a research forester assigned to the Station's research unit studying the regeneration of California forests, with headquarters at Redding, Calif. **OLE T. HELGERSON** is an associate professor of forestry, Department of Forest Science, Oregon State University, Corvallis, Oreg.

Publisher:

Pacific Southwest Research Station
P.O. Box 245, Berkeley, California 94701

September 1990

Mulches Aid In Regenerating California and Oregon Forests: Past, Present, and Future

Philip M. McDonald Ole T. Helgerson

CONTENTS

IN BRIEF . . .

McDonald, Philip M.; Helgerson, Ole T. 1990. **Mulches aid in regenerating California and Oregon forests: past, present, and future**. Gen. Tech. Rep. PSW-123. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 19 p.

Retrieval Terms: mulching, cost, effectiveness, conifer seedlings, survival, growth

In their quest to find a material that would effectively exclude weeds, favorably affect the micro-environment, and not cost too much, silviculturists have tried many materials to enhance conifer seedling survival in the past 30 years. Sheets of plastic, newspaper, and plywood; various thicknesses of bark, sawdust, sand, and straw; sprayed-on petroleum emulsion; and even large plastic buckets have been tested. Most have proven to be ineffective or costly or both.

Historically, mulches in Oregon and California have been applied to control grasses and forbs, but not shrubs, hardwoods, or ferns. Vigorous, stiff, upright stems, often by sprouts, or from root systems connected to living plants outside the mulched area, made mulching to control these kinds of vegetation futile. Methods for anchoring the mulches also were lacking, and too often a mulch would become loose, be flung over a pine or fir seedling by animals or the wind, and smother the seedling. Although small size and poor durability were part of the reason that taller weeds were not controlled by mulches, the main reason was cost and the sheer mechanics of transporting, installing, and maintaining large mulches over the many acres in reforestation units.

With few exceptions, mulches ranged from a few inches to 3-feet square and were too small to keep roots of weeds from growing under the mulch and usurping site resources. Mulches also were made of materials that had a short lifespan, usually 1 or 2 years, after which they broke up or decomposed. The small, short-lived mulches were neither large enough nor durable long enough to enhance conifer seedling growth. Increased survival for 1 or 2 years was all that was expected from them.

New developments include broadening the use of mulches to enhance conifer seedling growth. This has led to larger mulches and development of different materials having qualities unheard of in the past. Capability to last for up to 10 years, to become hot enough to kill undesirable seedlings that begin to grow on or below the mulch, and to "breathe" in the sense of allowing water to pass through to the soil, but to restrict its return to the air, are but a few of the characteristics needed to enhance growth.

This paper brings together much information on mulching in Oregon and California and contains numerous recommendations that match the various kinds of mulches to site conditions and types of vegetation. Mulch size, longevity, cost, specific weeds controlled, and strong points and limitations are presented.

INTRODUCTION

Mulching, the spreading of material around the base of a plant to mitigate adverse temperatures or moisture loss, control weeds, or enhance soil structure and fertility, has been an accepted horticultural practice for at least three centuries in Europe (Waggoner and others 1960). However, mulches have been applied in forestry in the Western United States for only about the past 30 years. Silvicultural literature, particularly during the past decade, increasingly refers to mulches for controlling competing vegetation in young conifer plantations *(fig. 1)*. Category of mulch (sheets of material, upright coverings, unconsolidated material), size of mulch (a few inches to many feet), cost of material (a few pennies to several dollars per seedling), longevity of the mulch (2 months to at least 5 years), keeping the mulches in place (slight to major problem), and their biological effectiveness (worthless to worthwhile) present a confusing picture to forest managers interested in their potential application. Some mulches are effective in some environments, some are not. Most are expensive, typically exceeding other vegetation control treatments in cost, but potentially offering equal biological effectiveness. Most are applied to control forbs and grasses, but in several studies they controlled shrub seedlings and at least in one instance, they controlled the sprouts of an aggressive hardwood, albeit at a high cost.

Figure 1—A 4-foot (1.2-m) square of ultraviolet stabilized polypropylene mulch should enhance Douglas-fir seedling survival on the Klamath National Forest, California.

New ideas, approaches, and materials now are being tried. Heretofore thought of as a temporary means of enhancing conifer seedling survival, mulches now are being considered as a technique for enhancing both survival and growth. New, porous, ultraviolet-light resistant materials that last long enough to enhance growth make this possible. New lightweight materials also are less expensive and easier to install.

This paper summarizes what is known about mulches in forestry. Its primary focus is California and Oregon, although information from other western states and foreign countries is presented when appropriate. The paper discusses the plantation environment, identifies the different categories of mulches, and describes their effect on the seedling's operational environment. The paper then presents information on the effectiveness and cost of mulching trials; gives some new ideas that hold promise for the future; and ends with specific recommendations including the need for, and a description of, an ideal silvicultural mulch. Throughout, special attention is given to biological effectiveness; longevity of the mulch; and cost of mulch material, installation, and maintenance.

OPERATIONAL ENVIRONMENT OF PLANTATIONS

The setting for this paper is in new plantations, mostly of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) and ponderosa pine *(Pinus ponderosa* Dougl. ex Laws. var. *ponderosa)*, in areas where a decision already has been made to prepare the site, plant seedlings, and do whatever else is necessary to establish a new forest. Although such areas support other forest uses such as wildlife and livestock grazing, the primary objective is reforestation. Consequently, the perspective of this paper is that most of the merchantable volume has been harvested and that slash and competing vegetation have been removed during harvesting and site preparation. Although covered with bits of twigs, branches, leaves, and other organic material, the soil surface of planted areas is temporarily free of living vegetation.

The need for mulching and the type of mulch to use can be determined by assessing the seedling's operational environment within a reforestation unit. The operational environment is determined by five factors that directly influence survival and growth: moisture, temperature, light, chemicals (nutrients and toxic effects), and mechanical damage (Greaves 1978, Spomer 1973). Any one of these can limit seedling survival. Within this framework, the biological usefulness of mulches for enhancing seedling survival can be determined by answering three questions: What part of the operational environment limits seedling survival or growth? Will a specific type of mulching lessen the negative impact of these factors? Will mulching make other parts of the operational environment, such as mechanical damage or the thermal regime, more limiting for survival and growth?

In northern California and southwest Oregon, water availability is the component of the operational environment that most often limits conifer seedling survival and growth (Atzet 1982, Helms 1976). Water availability is a function of supply and demand. As such, it depends on the regional climate, local climate, and microclimate surrounding the seedling, in conjunction with other influences on the operational environment, such as competing vegetation and soil characteristics.

On a regional level, the climate in which forests grow in northern California and southwest Oregon is largely determined by events in the atmosphere over the Pacific Ocean, and specifically the seasonal balance between the Pacific High pressure cell to the south and the Aleutian Low pressure cell to the north (Shumway 1981). Summers are warm and dry and winters are cool and wet, with precipitation ranging from more than 150 inches (3750 mm) to less than 30 inches (750 mm) per year (Fowells 1965) depending on latitude, altitude, and distance inland (Froelich and others 1982, Shumway 1981). When plants are actively growing, demand for water typically exceeds water available from the soil and from precipitation. These water deficits are smallest in the fog belt near the Pacific coast and increase with distance inland as the climate becomes more continental and less marine (Franklin and Dyrness 1973, Major 1977, Shumway 1981, Whittaker 1960).

Topography affects water availability in the local climate around a seedling. In the Coast and the Cascade-Sierra Nevada Ranges, precipitation increases with elevation, although for comparable exposure and elevations precipitation tends to be less inland. Between these mountain ranges lies a narrow, discontinuous, low elevation corridor. Annual precipitation here is usually less than 50 inches (1250 mm) (Shumway 1981), and occasionally lower than 25 inches (625 mm) (Froelich and others 1982). In the mountains, individual ridges can also intercept precipitation (Major 1977), creating localized rainshadows (Froelich and others 1982).

Water demand is largely a function of solar radiation. In the immediate microclimate around a seedling, the latitude, slope, and aspect of a site determine the potential solar radiation received. For example, south-facing slopes receive more solar radiation during the dry season (Flint and Childs 1987a), have greater water demand (Minore and others 1984), and reach higher soil surface temperatures (Hallin 1968) than north-facing slopes. The actual solar radiation received, however, is reduced by absorption and scattering in the atmosphere, and affected by the exposure of the seedling to sunlight. The latter is determined by the size and shape of the reforestation unit with respect to surrounding topography and vegetation (Flint and Childs 1987a). Although the need for mulches is determined by the effects of climate on a seedling's operational environment, mulches influence seedling survival and growth by altering only the microclimate and other parts of the operational environment immediately surrounding the seedling.

COMPETING VEGETATION

Because site preparation can remove almost all vegetation, the plant community in young plantations tends to be that of early seral stages. Through natural selection over millions of years, many weed species are superbly adapted to dominate in newly disturbed areas. Herbaceous and woody weeds can remove enough soil water during the growing season to kill or reduce the growth of conifer seedlings (Hermann 1964), usually offsetting any benefits of shade (Helgerson 1988). Soil heat transfer in the seedling's microclimate is also adversely affected by water consumption of competing vegetation (Melton 1989). Dry soils often have lethally high surface temperatures and store less heat, thus offering less protection against frost. Early-maturing forbs and grasses are especially dangerous because they are widespread and remove water early in the growing season, thus denying water to seedlings later in the growing season when demand is greatest (White and Newton 1989). Experience strongly indicates that reforestation will fail on droughty sites when these competitors are present. The problem is most severe on sites away from the fog belt (Gratkowski and others 1979), especially on south-facing slopes (Minore and others 1984), although conifer seedlings growing amid herbaceous competition near the coast (Tung and others 1986) or inland on north-facing slopes can also show poor survival (Hunt 1963).

In a typical plantation on a site of average quality, the first plant species to reoccupy the site are those that rapidly regrow a photosynthesizing canopy from live root crowns, roots, rhizomes, or burls in the soil. These include sprouting hardwoods, such as Pacific madrone *(Arbutus menziesii* Pursh), tanoak *(Lithocarpus densiflorus* [H. & A.] Rehd.), chinkapin *(Castanopsis chrysophylla* [Dougl.] A. DC), and California black oak *(Quercus kelloggii* Newb.); shrubs such as *Arctostaphylos* and *Ceanothus* species, and bracken fern *(Pteridium aquilinum* [L.] Kuhn var. *pubescens* Underw.). Fueled by the remaining food reserves and root system of the parent, new growth starts soon after disturbance and often is rapid. After one growing season, for example, height of sprouts of the above species will range from 1 to 5 feet (0.3 to 1.5 m). After three to ten growing seasons, heights will range from 1 foot to more than 22 feet (6.7 m) *(table 1)*. Such heights indicate a high potential for dominating young conifer plantations.

The next class of plants to occupy the plantation are mostly forbs and grasses from seeds that blow in or are carried into the plantation in the fall. The forbs are those with adaptations that favor dissemination by the wind. Small lightweight seeds with large wings, and numbers large enough to saturate an area characterize such plants. Many are biennials. Triggered by fall moisture, the seeds germinate, grow 1 or 2 inches (2.5 to 5.0 cm) above ground, but 5 to 8 inches (12 to 20 cm) below, and overwinter as small inconspicuous plants. They resume growth in the spring, often when soil temperatures are still cold enough to inhibit root growth of conifer seedlings. Because their root

Table 1—*Growth of selected sprouting species in northern California and southwest Oregon*

Species	Location	Sprout dimensions[1]	Seasons of growth	References
		ft (m)		
Bigleaf maple	NW California	12.8 (3.9) ht.	3	Roy 1955
Pacific madrone	NW California	10.9 (3.1) ht.	3	Roy 1955
Pacific madrone	Oregon Siskiyous	7.0 (2.1) ht.	5-6	Tappeiner and others 1984
Pacific madrone	California Sierra Nevada	22.2 (6.8) ht. 10.2 (3.1) wth.	10	McDonald 1978
Tanoak	NW California	6.8 (2.1) ht.	3	Roy 1955
Tanoak	Oregon Siskiyous	10.3 (3.1) ht.	5-6	Tappeiner and others 1984
Tanoak	California Sierra Nevada	19.0 (5.8) ht. 10.2 (3.1) wth.	10	McDonald 1978
California black oak	California Sierra Nevada	20.0 (6.1) ht. 9.4 (2.9) wth.	10	McDonald 1978
Whiteleaf manzanita	California Sierra Nevada	3.8 (1.1) ht.	10	Oliver[2]
Deerbrush	California Sierra Nevada	5.7 (1.7) ht.	10	Oliver[2]
Bracken	California	1.1 (0.3) ht.	5	McDonald[2]

[1]ht. = height; wth. = width.
[2]Unpublished data on file. Pacific Southwest Research Station, Redding, California.

systems are intact and vigorous, and some photosynthetic apparatus already is in place, these plants grow vigorously. In a new plantation on a good site in the northern Sierra Nevada, for example, peak density of bull thistle *(Cirsium vulgare* [Savi] Ten.) was 34,000 seedlings per acre (84,014/ha) with a height of 1.9 feet (0.6 m) (McDonald and Tappeiner 1986).

The grasses can be both annuals and perennials, with seeds carried into the reforestation area by the wind or on the feet, feathers, and fur of animals. Grasses possess numerous adaptations that allow them to compete vigorously for site resources (Logan 1982), and to establish large populations. In a plantation on a good site in northern California, for example, cheatgrass *(Bromus tectorum* L.) numbered 44,500 plants per acre (109,900/ha), 0.9 feet (0.3 m) tall after 5 years.[1]

The third class of plants appears the first spring after disturbance. These are shrub seedlings from such genera as *Rhamnus, Garrya, Ceanothus* and *Arctostaphylos*, and from herbaceous species like *Vicia* and *Lupinus* whose seeds have lain dormant in the soil for years. Dormancy enables a species to wait out periods of time when conditions are unfavorable for establishment and growth. Populations of such species can be huge (McDonald and Fiddler 1986). Fire often increases the abundance and growth of these species by inducing germination and preparing an advantageous seed bed. Most seeds usually germinate the first spring, but some also germinate the next year or two. The number of dormant seeds in the soil can also be huge. For example, Weatherspoon (1988) sampled vertical profiles of dormant seeds of snowbrush *(Ceanothus velutinus* Dougl. ex Hook.) in duff and soil beneath a 70-year-old stand of California white fir *(Abies concolor* var. *lowiana* [Gord.] Lemm.), and found a mean density of 5,180,000 seeds per acre (12,794,600/ha). A peak density of 1,120,000 seeds per acre (2,766,400/ha) occurred in the lower inch (2.5 cm) of duff alone.

[1]Unpublished data on file, Pacific Southwest Research Station, Redding, California.

MULCHES: CHARACTERISTICS AND EFFECTS ON ENVIRONMENT

Mulches used in reforestation fall into three categories: sheets of material, unconsolidated or loose material, and upright coverings. Sheets include various kinds of paper, plastic, and polyester materials. The use of unconsolidated materials involves placing of inorganic substances (sand, cinders, light-colored stones) or organic materials (sawdust or bark) around planted seedlings. Upright coverings consist primarily of buckets or boxes that are placed directly over sprouting stumps. Sheet materials are the largest category and the one most often applied to young plantations in Oregon and California.

Mulches can alter a conifer seedling's operational environment in several ways. Some are beneficial, others are not. A primary effect of mulching is the changing of the energy balance in the microclimate surrounding the seedling. From this perspective, mulching is defined as the application or creation of any soil cover that constitutes a barrier to the exchange of heat or vapor (Rosenberg 1974). Heat energy moves through the seedlings's environment in several ways. It is absorbed or reflected as shortwave radiation (visible light), and absorbed and emitted at the soil surface as longwave (infrared) radiation. It can be gained or lost as latent heat—a result of the condensation or evaporation of water, and it also can be transported by air movement (convection), and by direct contact (conduction). The way that a mulch modifies the energy flow within a seedling's operational environment depends on characteristics of the mulch. However, the overall effect of mulch on seedling survival and growth also depends on soil, weed, and seedling characteristics.

Effect of Mulches on Soil Energy Balance

The effect of different mulch materials (black polyethylene, kraft paper, hay) on the soil energy balance *(fig. 2)* is seen in temperature profiles measured near noon during clear weather on June 11, 1959 for a fine sandy loam soil (Waggoner and others 1960). Depending on the characteristics of the mulch, incoming solar energy (R_i) that is not converted into latent heat (W↑) can warm the soil (G↓) with heat from the mulch, be reflected or reradiated as outgoing radiation (R_o), or exchanged with air (A↑) by conduction or convection. The surface temperature of the black polyethylene is greatest because it absorbs much incoming solar energy and reflects and reradiates less heat than the other mulches. It conducts more energy to air above it, prevents cooling of the soil by blocking evaporation, and would warm the soil more if not for the intervening air gap between it and the soil.

Translucent and especially clear mulches warm the soil by direct radiation on the soil surface and by blockage of reradiation (the greenhouse effect). The kraft paper has about the same amount of energy reflected, reradiated, and lost to the atmosphere as black polyethylene, but allows some loss of water from the soil and does not transfer as much heat to it. The hay absorbs nearly the same amount of radiation as bare soil, but has a high surface temperature due to its poor conductivity and heat storage. Consequently, hay loses most incoming solar energy as reradiation or conduction to the atmosphere. The underlying soil remains cool when the hay surface is hot. At night, the hay

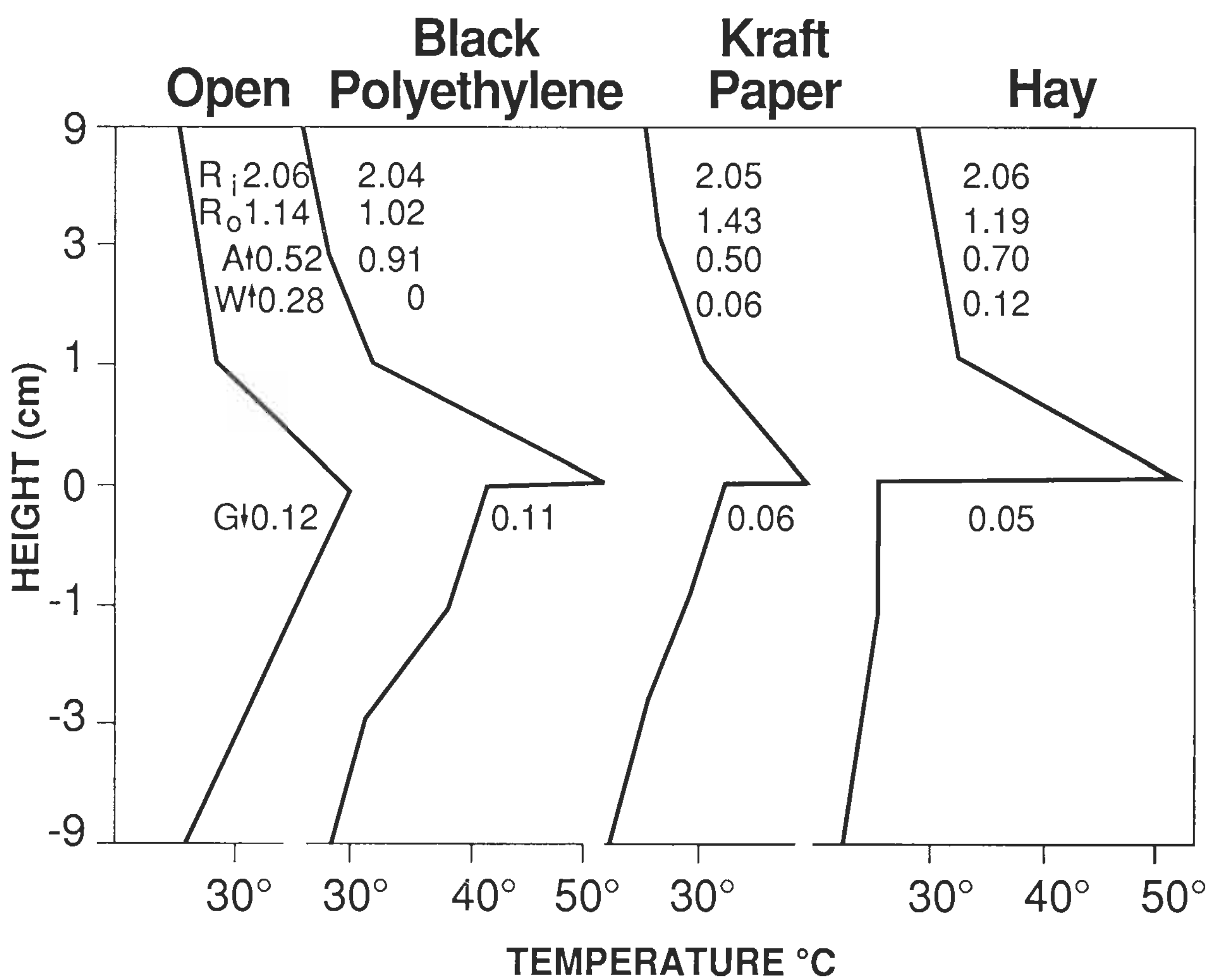

Figure 2—Temperature profiles and distribution of energy for bare soil and mulches of black polyethylene plastic, kraft paper, and hay. Measured at 1144 hours, June 11, 1959. Energy exchange (Langleys) noted as incoming radiation (R_i); outgoing radiation (reflected and reradiated) (R_o); energy exchanged with the air by conduction and convection (A↑); latent heat exchange (W↑); and conduction to and from the soil (G↓). Direction of exchange is noted by arrows (Waggoner and others 1960).

surface is prone to frost, while the soil stays warm.

In general, sheet mulches tend to dampen annual and daily temperature fluctuations in the soil by either raising minimum temperatures or lowering maximum values or both. Dark materials tend to warm the soil, with greater warming from clear or translucent material. Light-colored materials cool the soil according to their reflectivity, with greatest cooling from aluminum (Davies 1988a, Jacks and others 1955, Waggoner and others 1960). Changes in soil temperature profiles may not directly affect seedling survival (Davies 1988a), although mulching that increases soil warmth may help decrease the incidence of frost damage (Melton 1989). Mulches of kraft paper reduced frost heaving of planted ponderosa pine seedlings (Hermann 1965).

Surface temperatures of dry, dark organic mulches (Jacks and others 1955) and sheet mulches (Flint and Childs 1987b) can become high enough to kill stem tissue, although seedlings should not be damaged if the mulch does not contact the seedling stem (Flint and Childs 1987b).

Certain aspects of the soil energy balance relate directly to soil water content. For example, as soil moisture increases (by mulching or otherwise), heat capacity and thermal conductivity are increased, which further ameliorates soil temperature extremes.

Effect of Mulches on Water

Mulches tend to exchange less latent heat than bare soil. A loose mulch reduced surface evaporation and increased water availability to poplar *(Populus* spp.) seedlings in pots (Sultan and others 1986). Porous mulches do not block as much water as impermeable mulches, but can allow greater recharge of soil moisture from precipitation (Davies 1988a, Jacks and others 1955), although rewetting of soil was observed under large impermeable plastic mulches (Davies 1987). On sloping ground, felt mulches in poor contact with the soil may wick water away from seedlings (McNabb 1985)—a process that explained dry soil in spring beneath 10-foot square polyester mats in northern California (McDonald and others 1989). Much literature shows that loose organic mulches improve water absorption and reduce soil erosion (Overhulser 1955). However, on poorly drained sites, anaerobic conditions can be created or worsened by sheet (Davies 1988b) and loose mulches (Davies 1987).

In addition to blocking evaporation from the soil surface, mulches increase the amount of water available to seedlings by suppressing competing vegetation. A literature review (Jacks and others 1955) and field studies of Douglas-fir seedlings in southwest Oregon (Melton 1989) indicated that preventing transpiration by competing plants was the most important means for increasing water availability. This is because bare soil forms its own mulch as it dries downward (Rosenberg 1974), whereas leaves, stems, and roots of plants offer a much more effective conduit for transport of water from subsurface soil to the atmosphere. On a droughty site in southwest Oregon (clay loam soils, 15 to 20 inches of annual precipitation) covered with grass and forbs, paper mulches kept soil moisture tension above -15 atmospheres throughout one growing season (Hermann 1965) *(fig. 3)*. Here, first-year survival of mulched ponderosa pine seedlings was twice that of unmulched seedlings. Light-colored mulches such as kraft paper and aluminum foil have, however,

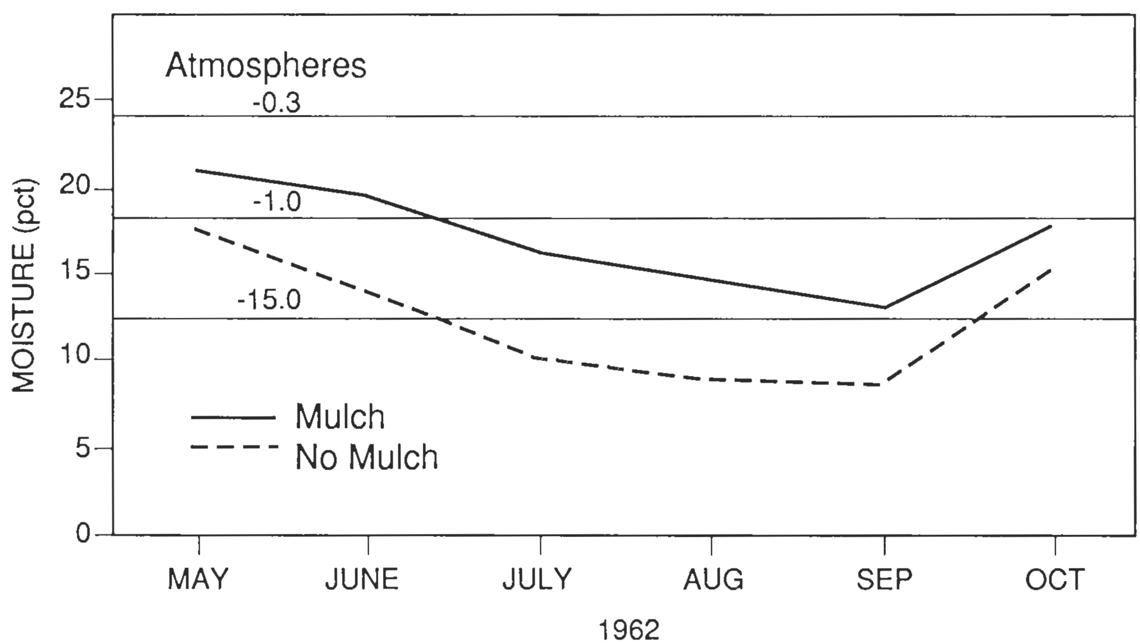

Figure 3—Mean gravimetric soil moisture (n = 2) at 12-inch depth near 2-0 ponderosa pine seedlings with and without paper mulch. Soil moisture contents for moisture tensions of -0.3, -1, and -15 atmospheres were determined with pressure membrane equipment.

increased transpiration of overhead leaves by about 10 percent because of reflected radiation (Waggoner and others 1960).

Effect of Mulches on Weeds

In reforestation, mulches appear to suppress competing vegetation primarily by blocking light necessary for photosynthesis, and to a lesser extent, by mechanically impeding growth (Clarkson and Frazier 1957). Translucent or clear mulches such as white or clear polyethylene allow enough sunlight for growth to reach underlying weeds. Although water use by underlying weeds is greatly restricted, the growing weeds can displace the mulch, ruining its effect (Clarkson and Frazier 1957, Davies 1988a). However, if no weeds are present, conifer seedlings may benefit from warmer soil. Porous mulches may allow weed seeds to germinate on their surfaces (Davies 1988a, Jacks and others 1955), although the high surface temperatures associated with dark mulches (Jacks and others 1955) may kill weeds growing on or under the mulch material. Mulches of unconsolidated material, such as chips or sawdust, block surface evaporation and in general control weeds in direct proportion to their thickness. In Great Britain, however, 4 inches (10 cm) of bark mulch failed to control herbaceous weeds (Davies 1987). Herbaceous weeds growing near the edges of plastic mulches were larger than those away from the mulch, showing increased root growth and large root volumes under the mulch (Davies 1988b).

To effectively control weeds, mulches must be applied early, remain intact, and be of sufficient size. Mulches are more effective when applied before early-maturing vegetation has depleted soil water (Davies 1987). Weak or short-lived materials do not control woody or herbaceous plants long enough for conifer seedlings to capture necessary site resources. In this regard, black polyethylene 5 mil (125 micrometers) thick is more durable on rough ground than 1.6 mil (40 micrometers) thick material, and film made from virgin polymer containing 2 to 5 percent carbon is regarded as being more opaque and stable to ultraviolet light than recycled material with less carbon (Davies 1987). In Great Britain, growth of sycamore *(Acer pseudoplatanus* L.) surrounded by grass increased as the size of the weed-free area increased from 1 by 1 foot to 6 by 6 feet (0.3 by 0.3 m to 1.8 by 1.8 m) with similar results for mulch or herbicide treatments. Controlling weeds near the edge of the mulch with herbicides increased seedling growth more than singly using mulches or herbicides for weed-free areas up to 4 by 4 feet (1.2 by 1.2 m) (Davies 1987). Near the Oregon coast, mulching and spot spraying of herbicides for 3 by 3 feet or 0.9 by 0.9 m similarly increased survival of planted Douglas-fir seedlings in a community dominated by grass (Tung and others 1986).

Soil and Seedling Type

The effectiveness of mulching also depends on soil and seedling type. Mulching appears to be more effective on well-drained sandy or gravelly soils as compared to clayey or loamy soils (Davies 1988b). On a pumice forest soil, however, Lopushinsky and Beebe (1976) noted no difference in moisture contents between soils mulched with black plastic and unmulched soils. Mulching seems to increase survival more for poor quality than good quality seedlings (Davies 1988b). Hermann (1967) noted that mulches increased survival more for ponderosa pine grown from a mesic seed source than that from a xeric source.

Other Effects

Both sheet and unconsolidated mulches can increase soil tilth (Jacks and others 1955). Agricultural studies show increased microbial activity and nutrient availability under dark sheet mulches (Waggoner and others 1960). Loose organic mulches can increase, but more typically decrease nutrient availability because of high carbon/nitrogen ratios, requiring application of nitrogen and sometimes phosphorus to maintain crop yields (Roberts and Mellenthin 1959). Soluble products from asphalt- or tar-coated paper conceivably could contribute several pounds per acre to the environment. Tar-coated products have been reported to decrease crop growth. And naturally occurring chemicals in some loose organic mulches have been suspected of adversely affecting plant growth (Jacks and others 1955). Sheet mulches can be dislodged by cattle (Hermann 1964), big game and gravity on steeper slopes (Schaefer-Jones 1989), and wind—mechanically damaging or blocking light to seedlings. Sheet mulches also provide habitat for voles (Davies 1988b), which can damage conifer seedlings.

MULCHES: EFFECTIVENESS, COST, AND DURABILITY

Chronological Development in Oregon

The first documented trials with mulches on forest land in Oregon were installed in 1958, 1959, and 1960 in southwest Oregon. They compared survival of mulched 2-0 Douglas-fir seedlings to unmulched controls. Study sites were judged as harsh because of relatively shallow, droughty soils and competition from forbs and grasses. Mulches were various types of paper or plastic and of various sizes:

Material	Size		Cost
15 lb black builder's felt	18 in. by 18 in.	36 in. by 36 in.	0.7 cents/ft^2
1 1/4 mil black polyethylene	same	same	0.7 cents/ft^2
2 ply kraft paper (tar, cords)	same	same	1.0 cents/ft^2
Pineapple mulch paper	same	same	0.3 cents/ft^2
Lightweight kraft paper with polyethylene on one side	same	same	0.7 cents/ft^2
Kraft (asphalt interlined)	24 in. by 24 in.		0.4 cents/ft^2

After 2 years, survival ranged from 7 percent without mulch to 32 percent with 18- by 18-inch (46- by 46-cm) mulch to 62 percent with 36- by 36-inch (91- by 91-cm) mulch (Newton 1961). For the 24- by 24-inch (61- by 61-cm) kraft paper (asphalt interlined), seedling survival after 3 years was 12 percent without mulch and 56 percent with mulch, a highly significant difference ($p < 0.01$) (Hermann 1964). Durability of the lightweight, polyethylene-coated kraft paper was rated as very poor, that of the asphalt interlined kraft paper as poor, and the 15-pound (7-kg) felt as fair. The other materials were rated "good" after two growing seasons.

A related study with similar competing vegetation in a similar environment, also with 2-0 Douglas-fir in southwestern Oregon, quantified survival according to mulches 18 inches (46 cm), 27 inches (68 cm), and 36 inches (91 cm) square, and to an untreated control. The mulch was asphalt interlined kraft paper. After two growing seasons, survival ranged from 10 to 60 percent and related significantly ($p < 0.01$) to presence and size of mulch (Bradley 1962). Cost also related directly to mulch size, and ranged from 5.3 cents to 10.5 cents per sheet after placement around trees. However, after two growing seasons, the mulch material had broken up in some parts of the study area and had completely decomposed in others.

In 1961, Hunt (1963) tested most of the paper mulches noted previously plus other mulches including newspaper (six sheets), scalping and sawdust, and clear plastic sheeting. All treatments were about 24 inches square except newspaper which was 23 by 32 inches (58 by 80 cm). He concluded that mulching greatly increased first-year survival of three types of conifer seedlings in dense herbaceous vegetation in southwestern Oregon.

Early studies (1960) also included ponderosa pine, but these were planted at elevations around 4000 feet (1220 m) in habitats dominated by forbs and both annual and perennial grasses in southern Oregon. The pine seedlings had grown for 2 years in a nursery and were large and healthy. The mulch was asphalt interlined kraft paper. After two growing seasons, survival was significantly ($p < 0.01$) greater for mulched seedlings (75 percent) than for unmulched seedlings (36 percent) (Hermann 1965). After five growing seasons, survival was 71 versus 32 percent (Hermann 1967).

Mulching trials continued in the 1970's, with renewed interest in the mid-1980s. Both old and new materials were tried. In April 1980, near Roseburg, Oregon, 3- by 3-foot (0.9- by 0.9-m) squares of laminated (kraft paper-asphalt-kraft paper) mulches were installed to test their effect on survival of 2-0 Douglas-fir and ponderosa pine seedlings planted in an old pasture dominated by grass. After two growing seasons, survival of mulched seedlings ranged from 76 to 98 percent as compared to 0 to 22 percent for controls. Application cost (1981) including material was $400 per acre ($988/ha) for mulching (Hobbs 1982).

Near Brookings, Oregon in 1982, rapidly growing sprouts of tanoak created an almost hopeless environment for establishing plantations of Douglas-fir. To control these sprouts, large 15-gallon (68-l) black plastic buckets with handles and lips were installed over tanoak stumps immediately after cutting and the burning of slash. In many instances, grubbing of debris and leveling of ground (slopes were 20 to 50 percent) was needed to get the buckets in the ground and around the burl. In some instances where there were clumps of stumps, the buckets did not fit very well, and extra care was taken to bend them around the stumps. Almost always, the bucket was nailed to the stump. Costs were high; each bucket cost about $2.00, and installation was about 100 buckets per day for a crew of five. After 6 months, the treatment was judged as ineffective—too many sprouts were coming up around the buckets, apparently from dormant buds deep on the root burl. A few buckets were checked after 1 year, and tanoak sprouts were found coiled inside. They were pale yellow, but still alive (Sallander 1989).

In desperation, another trial was instigated. This time, large sheets of plastic 16 by 24 feet (5 by 7 m) were stretched over the ground, stumps and all, and weighted down with copious amounts of debris. Edges of the plastic were buried in trenches and backfilled. After one summer, the plastic became brittle and torn. It then flipped over seedlings, killing them. This costly technique was abandoned (Sallander 1989).

In 1982, a study on a south-facing hillside near Coos Bay, Oregon, assessed 3- by 3-foot paper mulches installed around 2-0 Douglas-fir seedlings in heavy grass. After three growing seasons, survival of Douglas-fir seedlings, given a single mulching, repeated mulching, or a single spraying of glyphosate, was nearly equal, greatly exceeding untreated controls, but about one-third less than seedlings in grass sprayed twice with glyphosate. During the first year, almost 70 percent of mulches needed straightening and replacement at 3-week intervals to counter damage by elk (Tung and others 1986).

Mulching with newspaper in southwest Oregon increased first-year survival of low-vigor, 2-0 Douglas-fir seedlings planted on a droughty, low-elevation site. The mulch was applied by overlapping four sets (each of 10-16 sheets) of open newspapers on a scalped area around each seedling *(fig. 4)*. Woody debris or clumps of soil were thrown on the newspaper to hold it in place. Rain also matted the paper to the bare soil and provided additional anchoring. The paper appeared capable of lasting for two growing seasons. Material costs (1985) were about 5 cents per seedling, based on a cost of $10 per hundredweight for newspaper from recycling companies. Estimated total cost per seedling ranged between 25 and 35 cents, depending on terrain and number of seedlings mulched per acre (Main 1985).

More recent trials have involved using polyester felts to control herbs and tanoak sprouts *(fig. 5)* or to alleviate competition from dense herbaceous vegetation by replacing a kraft paper mulch every 2 years *(fig. 6)*.

Chronological Development in California

In California, the first major mulching trials were near Ft. Bragg, in northern coastal California. Redwood *(Sequoia sempervirens* [D. Don] Endl.) and Douglas-fir seedlings were planted in spring 1961 and in several ensuing years. They were mulched with sawdust, shredded redwood bark, redwood chips, redwood needle litter, straw, and sand (Fritz and Rydelius 1966). The treated area ranged from 8- to 12-inch (20- to 30-cm) squares, 1 inch (2.5 cm) thick, except for straw which was "several" inches thick. Other materials included a medium thickness roofing paper, clear plastic, and pineapple paper (two layers of heavy kraft paper with tar in the middle). Initial trials

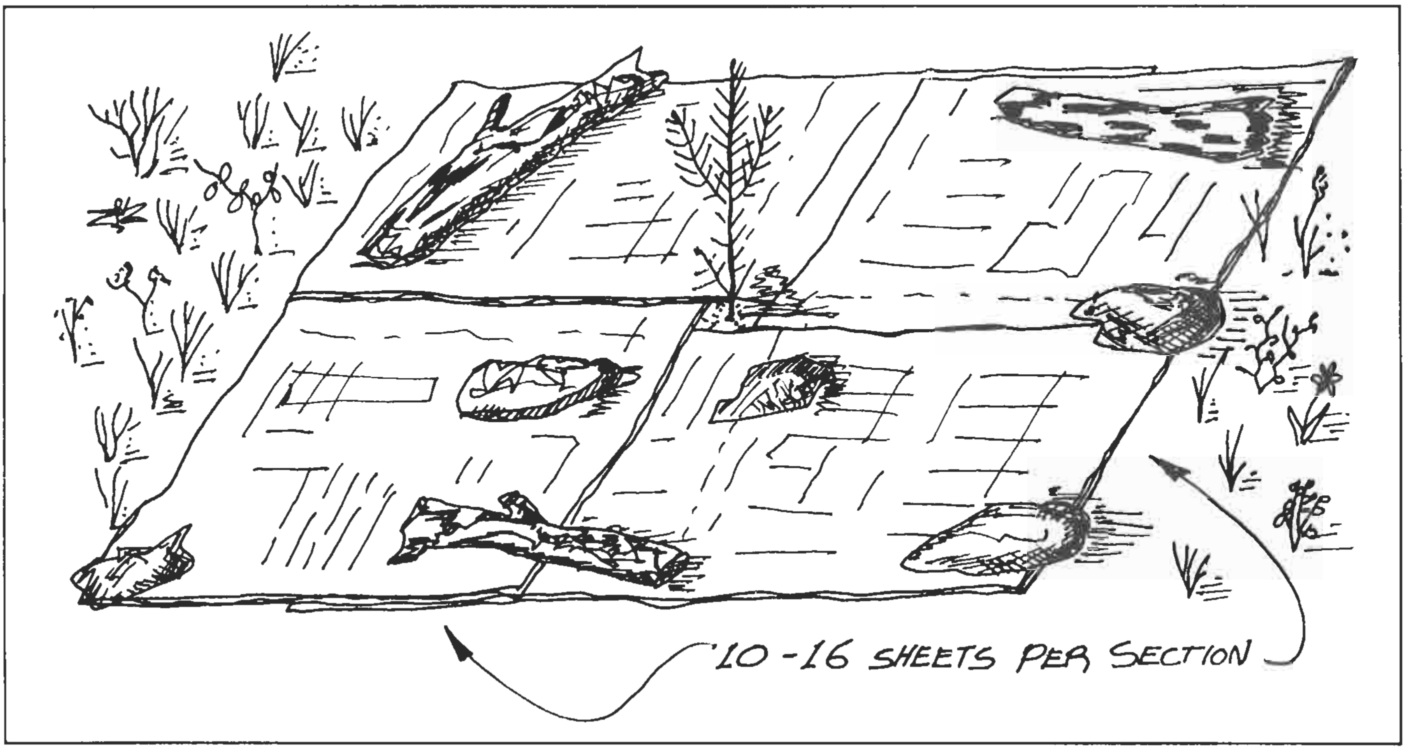

Figure 4—Diagram (not to scale) of four overlapping sets of opened newspaper applied as mulch.

Figure 5—A six-foot square of polyester felt, anchored with debris, near Glendale, Oregon, is keeping various herbaceous plants and tanoak sprouts away from the bole of a Douglas-fir sapling.

Figure 6—A new 30-inch-square kraft paper mulch has just replaced an old one (in place for two growing seasons) near Glendale, Oregon. Spring 1989.

were with 12- by 12-inch mulches, which later were increased to 36- by 36-inches for both papers. In general, the small mulches were ineffective for controlling herbs and grasses, although Douglas-fir seedling survival (60 percent) exceeded that of the control for both roofing paper and straw after three growing seasons. Survival of Douglas-fir mulched by the large size of roofing paper was 96 percent, while that of the control was 54 percent after two growing seasons. Chemicals from the woody particle mulches had no apparent negative effects on conifer seedlings. Durability of the roofing paper was excellent after 5 years, whereas that of the pineapple paper was poor after 1 year.

Some unusual materials have been tried as mulches. In the 1960's, a small trial with heavy 4- by 8-feet (1.2- by 2.4-m) sheets of plywood was installed in central California to control bearclover (*Chamaebatia foliolosa* Benth.), a tough, upright, woody plant capable of dominating most conifer plantations. After one growing season, the plywood killed the bearclover and increased soil moisture beneath it in midsummer (Tappeiner 1989).

After the initial burst of interest and application in the 1960's, the number of mulching trials in California decreased. Small-scale field trials continued, but these served mostly as demonstration areas.

Although not in California, a timely trial in Arizona in 1967-1968 tested some different mulching materials. Treatments were petroleum mulch (a water emulsion of petroleum resins sprayed on the ground), black polyethylene, clear polyethylene, volcanic cinders (2 inches or 5 cm deep), woodchips (2 inches or 5 cm deep), and control (Rietveld and Heidmann 1974). Each mulched spot was 18 inches (46 cm) square. After 1 year, only black polyethylene significantly improved ponderosa pine seedling height. Seedling survival, relative to the control, was not significantly improved. In all instances survival was below 43 percent—an unacceptable level. Most mulches were destroyed or rendered ineffective after one year. The petroleum mulch rapidly deteriorated from freezing, thawing, and solar radiation; the wood chip mulch washed away quickly; the clear polyethylene mulch acted as a greenhouse for weeds that developed vigorously beneath it and raised it from the ground. The clear polyethylene also disintegrated from solar radiation. Overall, the black polyethylene and cinder mulches were the most durable. Costs were not presented.

In north central California in the mid 1970's, 4- by 8-foot sheets of 3- to 6-mil black plastic and heavy kraft paper interlined with fiberglass and asphalt felt were used as mulch in an attempt to control bearclover. Neither material was satisfactory. Deer and cattle dragged both materials off the site, wind and gravity flung the mulches over the conifer seedlings, and sunlight broke them down. Even where the plastic remained, the bearclover, albeit weak and chlorotic, did not die. Both materials lasted only 1 to 2 years. The cost was $250 to $400 per acre ($618 to $988/ha) (Potter 1985).

Near Mad River, California in 1982, 30- by 30-inch (76- by 76-cm) mulches of fiber-reinforced, asphalt-laminated paper were installed to control grass in a young conifer plantation. "U"-shaped pins with small sticks placed horizontally in the "u" were used to anchor the mulch *(fig. 7)*. Vexar[2] tubes also were used to protect seedlings from browsing by deer *(fig. 8)*. At a rate of 435 mulches per acre (1075/ha), the mulch material, metal

Figure 7—A 30-inch square reinforced asphalt and paper mulch surrounding a 3-year-old ponderosa pine seedling on the Shasta-Trinity National Forest, California. The "U"-shaped pin and tongue depressor are used to hold down the corners of the mulch.

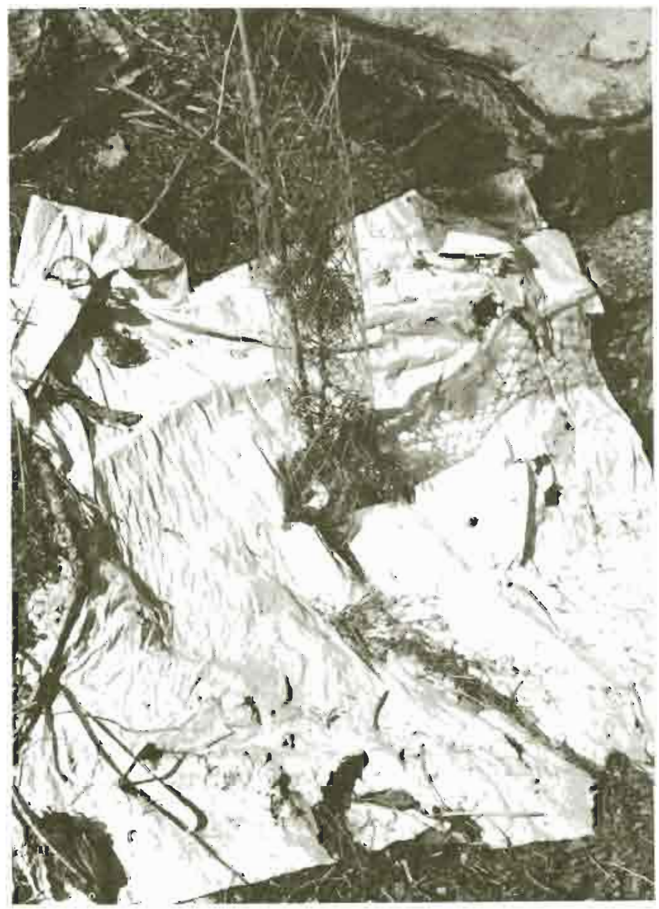

Figure 8—A 30-inch square of reinforced paper and Vexar tubing enhance the survival potential of this Douglas-fir seedling.

[2]Trade names and commercial products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

pins, and installation cost $164 per acre ($405/ha). Field checking indicated that even though the mulches began to deteriorate after a few months *(fig. 9)*, conifer seedling survival

Figure 9—This 4- by 4-foot (1.2- by 1.2-m) square of reinforced paper mulch is deteriorating badly after 1 year.

and soil moisture were greater with the mulches (Mathews 1983).

Mulches also have been used to control rapidly growing shrub species, by applying the mulch when the plants are small. In the northern Sierra Nevada, 4- x 4-ft squares of Hortopaper[2] (pressed peatmoss and cardboard) were used to control seedlings of deerbrush *(Ceanothus integerrimus* H. & A.) (McHenry and others 1988) *(fig. 10)*. The material cost a little over $0.03 per square foot ($0.32/m^2). After three growing seasons (1985-1987), most of the paper had disappeared or decomposed. Mulched Douglas-fir seedlings survived significantly better (87 percent) ($p < 0.05$) than controls (65 percent). However, survival of mulched ponderosa pine seedlings was not significantly better ($p > 0.05$) than that of control seedlings. After three growing seasons, deerbrush plants outside of the squares were over 62 inches (158 cm) tall and numbered 23,800 per acre (58,786/ha). The authors noted that the deerbrush shrubs "were rapidly closing over or into the conifers, and a rising incidence of pine reproduction weevil suggested competition-imposed moisture stress" of study seedlings.

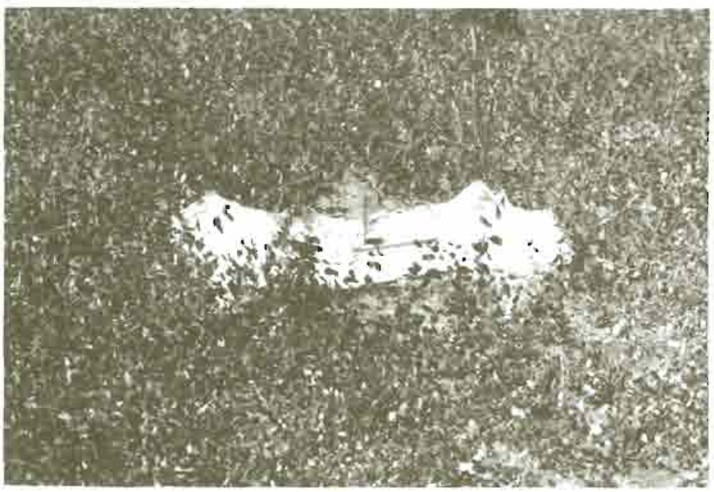

Figure 10—Although still alive, this ponderosa pine seedling is being impacted by roots from surrounding deerbrush seedlings.

Another mulch study near the small town of Pioneer in north central California was installed in 1986 to aid Jeffrey pine *(Pinus jeffreyi* Grev. & Balf.) seedlings. Competing vegetation was young plants from several species of forbs, grasses, and shrubs. Several mulch materials, some new and some old *(fig. 11)*, were evaluated for effectiveness, cost, and durability at a higher elevation (6400 feet or 1954 m) (Craig and McHenry 1988). Materials were:

Fortifiber[2] (asphalt laminated, reinforced kraft paper),

Phillips Duon[2] (ultraviolet stabilized nonwoven polypropylene),

Terra-Mat "E"[2] (continuous spun, needle-punched polyester),

Pac-Weave[2] (ultraviolet stabilized woven polypropylene),

Hortopaper (pressed peatmoss and cardboard)

Ultraviolet stabilized black polyethylene

Five to eight 8- by 4-inch L-shaped metal pins were used to hold down the Terra-Mat and Pac-Weave mulches. Other materials, all 4-feet square, were held down by burying corners of the mats in the soil and piling soil in places along the edges of the mats.

Results, by material, were:

Fortifiber: This material lasted a few weeks and then deteriorated rapidly, probably from a fungus when under snow. It tore with metal pins and had to be held down with soil and rocks. It cost $0.18 per mat with the "X" slit in the center, cut to size, and delivered.

Phillips Duon: "Durable" best describes this material—it showed no deterioration after 2 years. Edges of it (near the center "X") were abrasive and rubbed against pine seedling stems, subsequently killing them. A hot awl was necessary to create holes for hold-down pins. Duon cost $1.41 per mat and completely excluded competing vegetation.

Terra-Mat "E": Mulches of this material were durable, but showed some deterioration and shrinkage. Each mat cost $0.84.

Pac-Weave: Of the materials tested, this one gave the best results.

It was easy to apply, durable, and did not allow weeds to grow underneath. Shrinkage was minimal and precipitation seemed to pass through to the soil. Cost was $0.66 per mulch.

Hortopaper: Deer loved the taste of this material and after 2 weeks much of it had disappeared. In addition, this material was heavy, brittle, and tore easily. It cost $0.50 per 4- by 4-foot square.

Black Polyethylene: This material was easily installed with wire pins, but began to break up after 2 months. It cost $0.18 per square.

Cost per acre, using Pac-Weave as an example, was $327 per acre ($808/ha). Included in this figure are the costs of the material and wire hold-down pins, installation of the mulches, and maintenance of them for 2 years.

Based on this study, an extensive trial with Pac-Weave was installed on the Klamath National Forest. Six-foot squares of

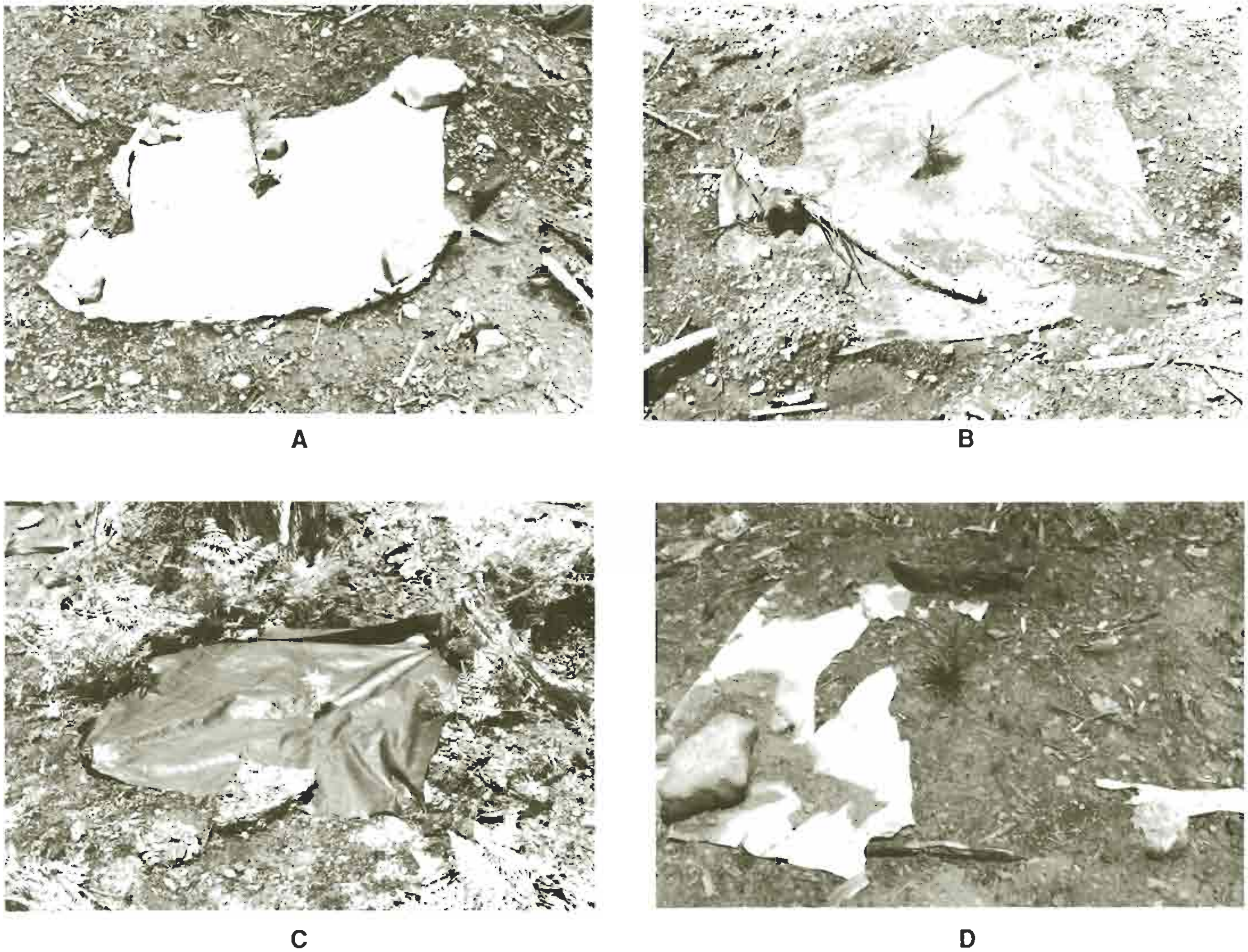

Figure 11—After 1 month several 4- by 4-foot (1.2- by 1.2-m) squares of different material show different methods of hold down and states of deterioration: *A.* Fortifiber, *B.* Phillips Duon, *C.* Pac-Weave, *D.* Hortopaper.

this material were applied over about 40 acres (16 ha) at a total cost of $350 per acre ($865/ha), including $1.37 per mulch and about $145 per acre ($358/ha) for installation (Busse 1989). Eight hold-down pins, each 8 to 9 inches long, anchored the mulches. Applied when the soil was moist, they became firmly anchored when the soil dried. Of particular interest was the soil moisture regime beneath the mulches at various times after the last storm in mid-May, as denoted at the 18-inch (45-cm) depth by gypsum blocks:

Elapsed time: (days)	Mulches	Control
	(pct moisture)	
20	97	64
40	93	39
60	78	18
80	60	13
100	42	8

Plainly, more moisture was present longer in the soil under mulches.

A mulch of unconsolidated material was installed near Mt. Shasta, California in fall 1986. Over 18 acres (7 ha) were disked and 1- to 3-inch (2.5- to 7.5-cm) chips of incense-cedar (*Libocedrus decurrens* Torr.) bark and wood were applied as mulch *(fig. 12)*. Chip depth was about 4 inches (10 cm) in the range of 2 to 7 inches (5 to 18 cm). Competing vegetation was mostly perennial grasses (*Stipa* and *Bromus* spp.) and occasional sprouts from greenleaf manzanita. Total cost (disking, chips, spreading the chips) was $620 per acre ($1532/ha). After one growing season, 2-0 ponderosa pine seedlings showed little difference relative to unmulched seedlings except that they were slightly chlorotic. After two growing seasons, the same few manzanita shrubs were present, but no others. Some grass was present in the mulched area, but "coming in strong" in the unmulched area. Survival of mulched seedlings was slightly better than that of unmulched seedlings. No differences in pine height were observed. Digging (shovel) in mulched areas in late summer revealed that more moisture was present in the upper 12 inches (30 cm) of soil, and pine seedlings had more fine roots

Figure 12—This 2-year-old ponderosa pine seedling, growing in a mulch of incense-cedar bark and chips, appears healthy and poised for rapid growth.

(Trevisan 1989).

Table 2 summarizes mulch materials and their performance in California and Oregon plantations.

NEW DEVELOPMENTS

Large Mulches for Growth

Because of benefits from mulching and the initial time and expense to purchase and install them, some silviculturists have asked: why not spend more money, make the mulches larger and durable, and have them keep out competing vegetation long enough to enhance conifer seedling growth as well as survival? Although large mulches are expensive, prorating the expense over a 5- to 10-year period is one way of adjusting cost. This led to investigation of larger mulches—at least 10- by 10-feet (3- by 3-m) square, a size predicated on previous work (Fiddler and McDonald 1987, McDonald and Fiddler 1986) that showed this size of treated area to be the minimum necessary to significantly ($p < 0.05$) enhance conifer seedling growth. Silviculturists asked further: with the advent of the new, tough, long-lasting polyester materials, why not use mulches to control *sprouting* shrubs?

In southwest Oregon, large (6.6 feet or 2.0 m) squares of Terra-Mat "E" were applied around planted Douglas-fir seedlings in 1985. Competing vegetation consisted primarily of tanoak sprouts. Slopes ranged from gentle to steep (> 60 percent). Snowfall in the area often exceeded 3 feet (0.9 m). Because the population of tanoak sprout clumps varied, mulches were placed between stumps (which almost always sprouted) in some instances, and directly over stumps in others. After 3 years, mulched Douglas-fir seedlings grew significantly greater in height and diameter than unmulched seedlings, especially at lower levels of tanoak sprout clump density (Harrington 1989). Passage of precipitation through the mulch did not appear to be a problem, presumably because the mulch matted to the soil and moisture discharged directly beneath it.

In another study installed in spring 1984 near Oroville, California, 10-foot (3-m) and 5-foot (1.5-m) squares of Terra-Mat "E" polyester felt were installed as mulch around 2-0 Douglas-fir seedlings. The mulch treatments were compared to manual release, which was done with a chainsaw at age 2 and again at age 3. Competing vegetation was vigorous sprouts of shrub tanoak *(Lithocarpus densiflorus* [H. & A.] Rehd. var. *echinoides* [R. Br.] Abrams) from recently cut and burned stumps.

Stimulated by light penetrating the mulches, dormant buds at the base of the shrub tanoak stems soon produced strong, erect sprouts. These stems began to push against the mats and soon formed a tangled mass. Because the mats became quite warm, the upper part of the mass usually turned yellow or brown from overheating. If near the middle of the mats, the sprouts caused a pronounced bulging of the material *(fig. 13)*; if near the edge, the sprouts would grow out from under the mulch, raise the edge, and allow the wind to fling the mulch over the seedlings, necessitating additional anchoring. After 4 years, however,

Figure 13—Stiff stems of shrub tanoak are causing the bulge in this large mulch of Terra-Mat "E".

Figure 14—Beneath the mulch of Terra-Mat "E" is a tangled mass of dead shrub tanoak sprouts.

Table 2—*Characteristics of mulch materials used primarily in California and Oregon*

Category/material	Size	Cost	Longevity	Weeds controlled	Benefits/limitations	References
	feet	*dollars*	*years*			
PAPER						
Kraft-asphalt-kraft paper Pineapple paper	2.5 by 2.5 to 3 by 3	164-435 per acre	<1-2	Annual and perennial herbs	Decomposes quickly; slides on slopes >50 pct; corners must be dug in on slopes; woody debris also used; anchor pins ineffective	Bradley 1962; Craig and McHenry 1988; Fritz and Rydelius 1966; Hermann 1964; Hobbs 1982; Mathews 1983; Newton 1961; Tung and others 1986
Newspaper	approx. 2.5 by 2.5	Estimated 0.25-0.35 per seedling for materials and installation	<1 - 2	Annual and perennial herbs	May mat to ground, better than interlined kraft paper, easy to carry in planting bags	Hunt 1963 Main 1985
Roofing paper	1 by 1 3 by 3	—	5	Annual and perennial herbs	—	Fritz and Rydelius 1966
Polyethylene coated kraft	1 by 1 3 by 3	—	<1	Annual and perennial herbs	Rapid decomposition limits effectiveness to first year	Newton 1961
Hortopaper (pressed peat-moss and cardboard)	4 by 4	material cost 0.50/sheet	<2 wk to 3 yr	Annual and perennial herbs, shrubs from seed	Heavy, brittle; tears easily; palatable to deer	Craig and McHenry 1988; McHenry and others 1988
PLASTIC SHEETS						
Black polyethylene 1.25 mil to 6 mil	1.5 by 1.5 4 by 8 1.3 by 2.0	Total cost 250-400/acre for 4- by 8-ft squares	1/6-2	Annual and perennial herbs	Durability variable–usually short; ineffective on bear clover, tanoak; displaced by cattle, deer; can smother seedlings	Craig and McHenry 1988; Newton 1961; Potter 1985; Rietveld and Heidmann 1974; Sallander 1989
Clear or white polyethylene	1.5 by 1.5	—	<1	Herbs	Promotes weed growth from underneath; no effect on seedling survival	Fritz and Rydelius 1966; Rietveld and Heidmann 1974
PLASTICS and FABRICS						
Terra-Mat "E" (nonwoven needle-punched polyester felt)	4 by 4 5 by 5 6.6 by 6.6 10 by 10	0.84 material cost for 4- by 4-ft mats; 1,398 and 2,752 per ac for larger material and installation	>4	Annual and perennial herbs	Slight shrinkage; some germination, but poor development of herbs on mat surface; may wick rain water away from seedlings unless good contact established w/soil; effective on tanoak sprouts	Craig and McHenry 1988; Harrington 1989; McDonald and others 1989
Phillips Duon	4 by 4	1.41 per sheet	<2	Herbs and shrubs	Good control; abrasive edges on "x" damage seedlings; difficult to insert hold-down pins; needs prepunched holes	Craig and McHenry 1988
Pac-Weave woven, ultra-violet stabilized polypropylene	4 by 4	1.37 ea for material, 350/ac installed	<2	Annual and perennial herbs	Good control; easy application; minimal shrinkage	Busse 1989
		0.66 ea for material, 327/ac installed and maintained for 2 yr				Craig and McHenry 1988
MISCELLANEOUS						
Petroleum-water emulsion	Covers 1.5 by 1.5	—	<1 yr	Herbs	Rapid decomposition	Heidmann and Rietveld 1974
Plastic buckets	15 gal.	2.00 ea.	—	Tanoak sprouts	Ineffective	Sallander 1989
Plywood	4 by 8	Very high	>5	Bearclover	Good control; cost, slope limitations	Tappeiner 1989
LOOSE MATERIALS						
Sawdust, bark chips, straw, sand	Covers 0.7 by 1	—	<2	Herbs	No toxicity noted from organic materials; ineffective	Fritz and Rydelius 1966
Wood chips	1.5 by 1.5	—	<1	Herbs	Washed away	Rietveld and Heidmann 1974
Wood and bark chips	18 acres, 2- to 7-inches thick	620/ac for disking site, spreading chips	>3	Controlled most grass and manzanita seedlings	Increased water in soil; some chlorosis of pines; pine growth not increased	Trevisan 1989

almost all of the sprouts under the mulches had died *(fig. 14)*. In the manual release treatment, the severed stems promptly sprouted with no noticeable decrease in numbers or vigor.

After four growing seasons, survival of Douglas-fir seedlings was 49 percent for 10-foot squares, 69 percent for 5-foot squares and 75 percent for manual release with no significant ($p > 0.05$) differences among treatments. Douglas-fir seedling stem caliper and height did not differ significantly among the mulching and manual release treatments (McDonald and others 1989). Comparison to untreated seedlings showed that neither mulches nor manual release were biologically effective. The mulches were not in close contact with the soil, and this apparently did not allow enough moisture to pass through. Lack of moisture, particularly beneath the large squares, increased mortality of Douglas-fir seedlings and decreased growth *(fig. 15)*. Although manual release removed tanoak material above ground, below-ground biomass apparently remained intact and capable of capturing scarce soil resources.

Cost of the mulch material was $6.39 each for 10-foot squares and $1.65 each for 5-foot squares. Installation cost $1.74 per square and keeping them in place averaged about $0.90 per square per year. With stocking of 200 seedlings per acre, costs would be $2752 per acre for the large mulches and $1398 per acre for the small mulches. Manual release with two applications cost $700 per acre, with at least one more application needed to have any chance of reducing tanoak vigor to the point of enhancing Douglas-fir seedling growth.

Another study on the Sequoia National Forest, begun in 1986, utilized nonwoven, needle-punched, polyester fabric applied around 1-0 ponderosa pine seedlings. This fabric was advertised to be "highly permeable to water" with water able to "easily pass in all directions—through and along the plane of the fabric." The fabric also was resistant to ultraviolet light and was dark gray to restrict light transmission. Size of mulches was 10- by 10-foot (3- by 3-m) squares. Two thicknesses of mulch were tested (0.15 and 0.22 inches or 0.38 and 0.56 cm); the thickest was supposed to last 10 years and the other, 5 years. The study site was located at 6400 feet (1921 m) elevation on a 30 percent slope with average annual precipitation of 35 inches (899 mm), about 80 percent of which falls as snow. Cutting the fabric to size, placing an "X" slit in the center, and installing the mulches around 208 seedlings took 94 hours. Carrying the heavy mulches uphill for about 0.25 mile (0.2 km) was exhausting, and digging in their corners and upper edges was time consuming. Stones and woody debris also were used to weight down the mulches and keep them in place.

In spring 1987, a detailed examination showed almost no mulch movement in spite of the steep slope and snow, no deterioration of the mulch material, and soil moisture beneath the mulch similar to that in unmulched soil nearby. Pine seedlings were classified as growing well *(fig. 16)* with almost no mortality. Grasses and forbs were also growing well at the edges of the mats, however.

After almost four growing seasons, the mulches showed little sign of deterioration and movement. No herbaceous or woody plants had grown under the mulches or germinated and grown through them. Pine seedlings averaged 3.5 feet (1.1 m) tall in mulched plots and 2.0 feet (0.6 m) in control plots. Current pine terminal shoots average about 15 inches (38 cm) in mulched plots, about 8 inches (20 cm) in control. Only one additional pine seedling in the entire study had died after the first year (Ahokas and Henry 1989).

New Mulch Materials

To increase mulch durability and permeability, products are being manufactured that resist deterioration by ultraviolet light and have holes large enough to pass air and water but small enough to prevent seeds or roots of undesirable plants from passing through. Seeds may germinate on the mulch surface, but are killed because of its dark color and high surface temperature. In a recent study in southwestern Oregon, Holen (1989) reported that a polypropylene material was lightweight, inexpensive ($160 per 2400-foot [720-m] roll, 6 feet [1.8 m] wide), permeable, excluded weeds, and showed no signs of deterioration after 2 years. Another recent trial in northern California is utilizing 10- by 10-foot squares of material made of a polypropylene and polyester blend that is supposed to last for at least 5 years. After

Figure 15—This 4-year-old Douglas-fir seedling, surrounded by 5 feet (1.5 m) of Terra-Mat "E" mulch, is not growing well. Examination in the spring indicated dry soil beneath the mulch.

Figure 16—A 1-year-old ponderosa pine seedling, surrounded by at least 5 feet (1.5 m) of nonwoven polyester mulch, appears to be off to a good start.

one growing season, the material appeared to be effective and durable (Bain 1989).

Areal Mulching to Increase Available Moisture

A new application of an old technique is to apply mulch over large areas early in the spring to increase available soil moisture and subsequent conifer seedling growth. In the spring of 1986, 6-mil black plastic was installed over entire 0.1-acre plots near Adin, California. The objective was to control annual grasses, principally cheatgrass, in a Jeffrey pine plantation, and to maintain soil moisture by reducing evaporation and transpiration. Soil moisture at time of installation was at or above field capacity. The plastic was installed in sheets with outer edges buried in shallow, back-filled trenches, and inner edges overlapped. Long nails with washers and pieces of slash were used to hold down the plastic. Overlapping edges received numerous hold-downs, other areas a few.

In mid-August both study plots were examined. No deterioration of the plastic or rips or holes were noticed. Air temperature under the plastic and soil moisture were ascertained both inside and outside of the plots. The surface of the plastic was hot and the air under it was warm and moist. The soil under the plastic was dark and moist throughout the profile. Outside the plots, however, the soil was hard and dry, at or near the wilting point. Needles of pine seedlings inside the plots were numerous, long, and a deep blue green; needles of pines outside the plots had less color. High soil moisture levels were also observed a month later under the patched plastic mulch. The color of the pines and the higher soil moisture and temperature beneath the mulch suggest that higher rates of nitrification may have been occurring as observed elsewhere by Waggoner and others (1960). The cost of the plastic for both plots was $213.[1] It took 2 men 2 days to install it. The plastic was removed in early fall.

Although of limited use in conventional plantations, this type of mulching could be worthwhile in specialized situations where high survival of conifers was desired on harsh sites, in campgrounds, and along roads. It could be particularly useful in "alley" planting—an agroforestry technique in which rows of closely spaced trees are grown in strips in fields of food and fodder (Winterbottom and Hazlewood 1987).

DISCUSSION

Based on the foregoing case histories, numerous interviews with experienced silviculturists, and the author's observations, several trends for mulching in California and Oregon are apparent.

In their quest to find a material that would effectively exclude weeds, favorably affect the micro-environment, and not cost too much, silviculturists have tried a remarkable number of materials to enhance conifer seedling survival in the past 30 years. Sheets of plastic, newspaper, and plywood; various thicknesses of bark, sawdust, sand, and straw; sprayed-on petroleum emulsion; and even large plastic buckets have been tested. Most have proven to be ineffective or costly or both. Of all the materials tried, the one used the most is that which was used first—kraft paper interlined with asphalt, and with or without fiberglass strands.

Enhancement of conifer seedling survival by excluding competing species of vegetation almost universally has been the goal when using mulches. In mostly summer-dry Oregon and California mulching reduces the drain on the most critical factor in the seedling's operational environment—soil water—mostly by reducing water lost by transpiring weeds, but also by impeding water lost by evaporation from the soil surface. With only a few exceptions, mulches ranged from a few inches to 3-feet square and were too small to keep roots of weeds from growing in from the side, under the mulch, and usurping site resources. Mulches also were made of materials that had a short lifespan, usually 1 or 2 years, after which they broke up or decomposed. The small, short-lived mulches were neither large enough nor durable long enough to enhance conifer seedling growth. Increased survival for 1 or 2 years was a common goal.

Another commonality of mulching trials in Oregon and California is the lack of statistically *significant* differences reported between mulch treatments and controls. Numerous are the words "conifer seedlings taller than seedlings in controls" and "soil more moist under mulches," but rare is there mention of differences being significant. Common also are statements that survival of conifer seedlings with mulches was markedly better than for those without. However, the level of survival for both mulched and unmulched seedlings was so low as to be unacceptable for both categories.

Historically, mulches in Oregon and California have been applied to control grasses and forbs, but not shrubs, hardwoods, or ferns. Vigorous, stiff, upright stems, often by sprouts, or from root systems connected to living plants outside the mulched area, made mulching to control these kinds of vegetation futile. Methods for anchoring the mulches also were lacking, and too often a mulch would become loose, be flung over a pine or fir seedling by animals or the wind, and smother the seedling. Although small size and poor durability were part of the reason that taller weeds were not controlled by mulches, the main reason was cost and the sheer mechanics of transporting, installing, and maintaining large mulches over acres and acres of reforestation units. Mulches also must be applied soon after planting, and this means that additional time must be spent installing them before soil moisture is depleted. Sometimes installation time simply is not available.

Relatively high cost is another consistent theme in mulching trials. As a whole, materials were of moderate cost; but installation costs were high, and if mulches were present for more than a few years, particularly on a steep slope, the maintenance cost was high also. Together, the costs of mulching tended to be

[1]Unpublished data on file, Pacific Southwest Research Station, Redding, California.

prohibitive, especially when compared to treatment such as herbicides.

From a landscape perspective, some managers have asked whether acres and acres of mulches in burned or harvested lands could negatively affect water quantity and quality, soil properties, and visual quality. On a recent burn in northern California, 150 long-lasting, 6- by 6-ft polypropylene mulches were applied to each acre *(fig. 17)* and together covered about 12 percent of the surface area. Native vegetation was plentiful between mulches. Given the micro-environmental effects noted earlier, it is difficult to envision significant negative consequences on soil or water properties arising from mulching. The effect on visual quality is another matter. Some observers might feel that the large number of mulches would detract from the natural landscape; other viewers, however, could feel relieved that the land was being reforested. A possible compromise would be to remove the mulches as soon as conifer seedling survival and growth reached desired levels.

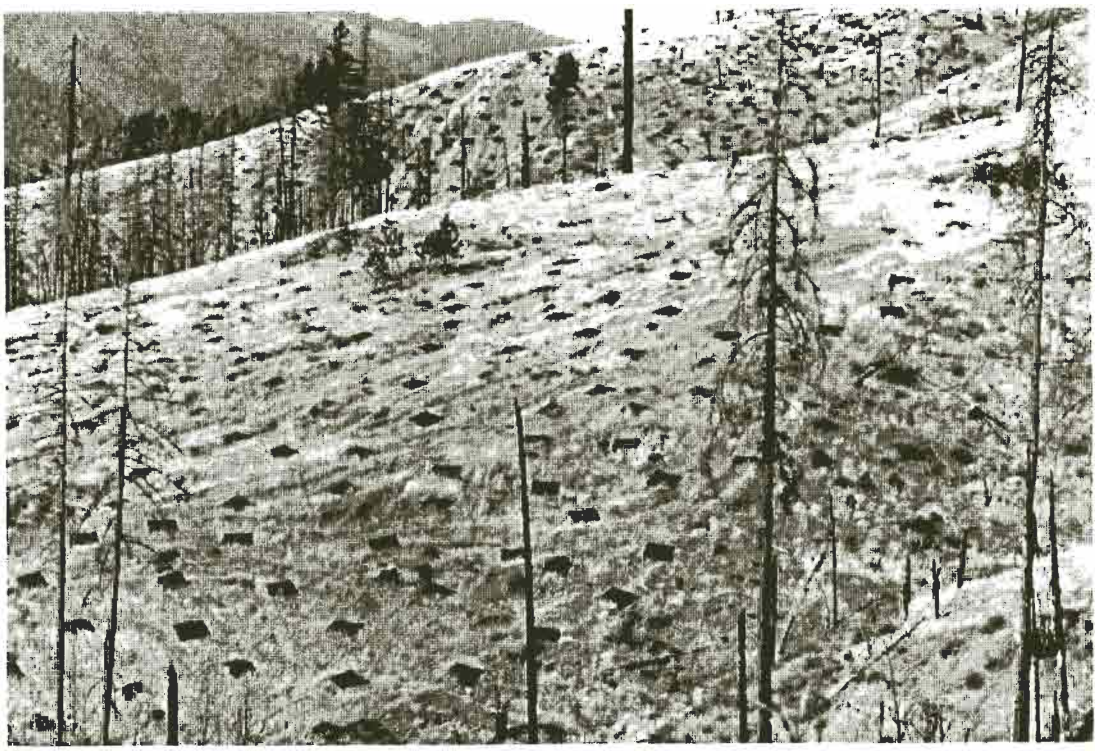

Figure 17—A landscape filled with post-fire vegetation and 6-foot squares of polypropylene mulches. Klamath National Forest, California.

RECOMMENDATIONS

What does the future hold for mulches as a silvicultural tool? Recommendations are keyed to site conditions, types of vegetation, mulch types, and combinations of the above. Characteristics of a badly needed mulch material keyed specifically to silviculture are presented.

Site Conditions

• Mulching will increase conifer seedling survival on south-facing slopes more than on north-facing slopes, at least where frost is not a factor. However, mulches can also aid conifer survival on north-facing slopes infested with herbaceous vegetation.

• Mulching will benefit conifer seedling survival most on soils with low water-holding ability.

• Although evaporative demand near the coast is less than on drier, more inland areas, mulching nevertheless has increased survival of conifer seedlings in the coastal setting.

• On steep slopes, mulching is more expensive because installation and maintenance costs increase.

• Mulching early in the spring minimizes water loss by evaporation from the soil and transpiration from competing vegetation.

Types of Vegetation

• Mulching effectively increases conifer seedling survival if herbaceous vegetation is present.

• In areas where shrub *seedlings* will be the primary competition, mulching will enhance conifer seedling survival, regardless of slope. Dark mulches will be necessary to kill shrub germinants.

• On areas infested with short *sprouts* from shrubs, it is biologically feasible to enhance conifer seedling survival with mulches, provided that the sprouts are first cut close to the ground.

Types of Mulch

• All mulch materials discussed in this paper have the potential to reduce water evaporation from the soil surface and to control weeds. Controlling weeds is more important.

• Short-lived mulches of paper or polyethylene can be used to enhance conifer seedling survival if herbaceous vegetation or seedlings of woody shrubs are present. Repeated mulching may be needed.

• Long-lived mulches of polypropylene or polyester can increase conifer seedling growth in addition to survival if at least 120 inches square.

• Large, long-lived mulches must have sufficient pore size to allow passage of air and water, or have good contact with the soil, or both. Impermeability may create a minor desert beneath large mulches on sloping ground. Installation costs tend to be high.

Combinations of Mulch Types, Environments, and Costs

Because the number of mulch types and the environments in which they will be placed are numerous, the above recommendations, in conjunction with *table 2*, give the reader a means to best match the choice of mulch to budgetary, biological, political, or other considerations. Still needed, however, are some general recommendations. These are:

• Apply mulches where weed control is necessary, and where herbicides or other techniques are unavailable or undesirable. Use mulches as a weed-control alternative or as an insurance measure.

• Where survival of conifer seedlings is all that is desired and the competition is primarily grass and forbs, use paper mulches at least 2.5-feet square for at least 2 years. Cost will be about $0.55 per seedling installed (1989 dollars). Larger mulches for longer times will give better control.

• For enhancing survival where aggressive forb and shrub competition is expected, use mulches having demonstrated strength and durability. Mulches should be at least 3.0 feet square and in place for at least 3 years. The estimated installation cost will be about $2.40 per seedling (1989 basis).

• Where growth enhancement of conifer seedlings is desired, and competing plants are dense perennial or annual grasses, forbs from below-ground rhizomes and roots, or sprouting shrubs, mulches in most instances are inferior to herbicides primarily for economical, but also for biological reasons. Use mulches if they are the only effective control technique available. Best results appear to be obtained from durable, permeable polypropylene mulches at least 6 feet square for grasses and 10 feet square for sprouting forbs and shrubs. Such mulches should allow growth to be at the potential of the site and cost between $2.40 and $6.00 (1989 basis) per seedling installed.

Need for a Silvicultural Mulch

Nearly all mulches discussed in this paper have been borrowed from various industries that range from agriculture to railbed construction. None have been engineered especially for silviculture. The latest polypropylene and polyester materials have many desirable characteristics, but more refinement is needed. Their development indicates, however, that the first real breakthrough for mulching on forest land in 25 years is possible. The ideal mulch for silviculture would . . .

• Be opaque to prevent weed growth under the mulch

• Be dark to create temperatures hot enough to kill germinants and sprouts that emerge under the mulch

• Be porous enough to allow water to infiltrate evenly through the mulch but still retard loss of water from under it

• Have thermal characteristics to maintain a favorable soil temperature regime

• Have the strength and durability to last until the conifer seedling was established and growing well, not tear at hold-down pins

• Be low in cost and lightweight for ease of transport and fast installation; be prefolded for easy fitting into tree-planting bags

• Be of a color(s) that blends into the landscape

• Not be toxic or give off toxic substances.

REFERENCES

Ahokas, Ann; Henry, Tom. 1989. **Sequoia National Forest, California Hot Springs, California**. Unpublished report on file at Pacific Southwest Research Station, Redding, CA.

Atzet, Tom. 1982. **Operational environment and factors limiting reforestation in the Siskiyou Mountains**. In: Hobbs, S.D.; Helgerson, O.T., eds. Proceedings of a workshop on reforestation of skeletal soils; 1981 November 17-19; Medford, OR. Corvallis: Forest Research Laboratory, Oregon State Univ.; 6-10.

Bain, Geoffrey C., Jr., Forester, Bureau of Land Management, Arcata Resource Area, Arcata, CA. [Telephone conversation with Philip M. McDonald]. July 1989.

Bradley, Robert F. 1962. **Survival of planted Douglas-fir seedlings on severe sites using the paper sheet mulch planting method**. Corvallis: Oregon State University; 78 p. M.F. Thesis.

Busse, Barbara, Silviculturist, Klamath National Forest, Etna, CA. [Telephone conversation with Philip M. McDonald]. November 1989.

Clarkson, V.A.; Frazier, W.A. 1957. **Plastic mulches for horticultural crops.** Station Bulletin 562. Corvallis: Oregon State College, Agricultural Experiment Station; 12 p.

Craig, Stewart; McHenry, Jim. 1988. **Mulch collars for preventing vegetation around conifer seedlings: a test of several methods.** In: Proceedings 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 142-150.

Davies, R.J. 1987. **Trees and weeds—weed control for successful tree establishment.** Forestry Commission, Handbook 2. London: Her Majesty's Stationery Office; 37 p.

Davies, R.J. 1988a. **Sheet mulching as an aid to broadleaved tree establishment. I. The effectiveness of various synthetic sheets compared.** Forestry 61(2): 89-105.

Davies, R.J. 1988b. **Sheet mulching as an aid to broadleaved tree establishment. II. Comparison of various sizes of black polythene mulch and herbicide treated spot.** Forestry 61(2): 107-124.

Fiddler, Gary O.; McDonald, Philip M. 1987. **Alternative treatments for releasing conifer seedlings: a study update.** In: Proceedings 8th annual forest vegetation management conference; 1986 November 4-6; Sacramento, CA. Redding, CA: Forest Vegetation Management Conference; 64-69.

Flint, A.L.; Childs, S.W. 1987a. **The effect of surrounding topography on receipt of solar radiation.** In: Forest hydrology and watershed management. Proceedings of the Vancouver Symposium; August 1987; Vancouver, BC; IAHS Publ. 167; 339-347.

Flint, L.E.; Childs, S.W. 1987b. **Effect of shading, mulching, and vegetation control on Douglas-fir seedling growth and soil water supply.** Forest Ecology and Management 18: 189-203.

Fowells, H.A. 1965. **Silvics of forest trees of the United States.** Agric. Handb. 271. Washington, DC: USDA Forest Service; 762 p.

Franklin, J.F.; Dyrness, C.T. 1973. **Natural vegetation of Oregon and Washington.** Gen. Tech. Rep. PNW-8. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 417 p.

Fritz, Emanuel; Rydelius, James A. 1966. **Redwood reforestation problems—an experimental approach to their solution.** Buena Park, CA: Foundation for American Resource Management; 130 p.

Froelich, H.A.; McNabb, D.H.; Gaweda, F. 1982. **Average annual precipitation in southwest Oregon 1960-1980.** EM 8220. Corvallis, OR: Oregon State University Extension Service; 8 p.

Gratkowski, H.; Jaskowski, R.; Armstrong, L. 1979. **Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil and 2,4-D.** Res. Paper PNW-256. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Greaves, R.D. 1978. **Ecological principles.** In: Cleary, B.D.; Greaves, R.D.; Hermann, R.K., eds. Regenerating Oregon's forests. Corvallis: Oregon State University Extension Service; 8-26.

Hallin, W.E. 1968. **Soil surface temperatures on cutovers in southwest Oregon.** Res. Note PNW-78. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 9 p.

Harrington, Timothy B. 1989. **Stand development and individual tree morphology and physiology of young Douglas-fir *(Pseudotsuga menziesii)* in association with tanoak *(Lithocarpus densiflorus)*.** Corvallis: Oregon State University; 185 p. Ph.D. dissertation.

Helgerson, Ole T. 1988. **Live versus dead shade—what's best for conifer seedlings?** In: Proceedings 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 157-167.

Helms, J.A. 1976. **Factors affecting net photosynthesis.** In: Cannell, M.G.R.; Last, F.T., eds. Tree physiology and yield improvement. New York: Academic Press; 55-78.

Hermann, Richard K. 1964. **Paper mulch for reforestation in southwestern Oregon.** Journal of Forestry 62(2): 98-101.

Hermann, Richard K. 1965. **Survival of planted ponderosa pine in southern Oregon.** Research Paper 2. Corvallis: Forest Research Laboratory, Oregon State University; 32 p.

Hermann, Richard K. 1967. **Paper mulch helps ponderosa pine seedlings get started on dry sites in Oregon.** Tree Planters' Notes 18(4): 1-2.

Hobbs, Steven D., Research Forester, Forestry Intensified Research Program, Medford, OR. [Personal communication with Philip M. McDonald]. Fall 1982.

Holen, Ivend D., Forester, Bureau of Land Management, Ashland Resource Area, Medford, OR. [Telephone conversation with Philip M. McDonald]. March 1989.

Hunt, Lee O. 1963. **Evaluation of various mulching materials used to improve plantation survival.** Tree Planters' Notes 57: 19-22.

Jacks, G.V.; Brind, W.D.; Smith, R. 1955. **Mulching.** Technical Communication No. 49. Farnham Royal, Bucks, England: Commonwealth Bureau of Soil Science, Commonwealth Agricultural Bureau; 87 p.

Logan, R. 1982. **Grass adaptations and their impact on conifer seedlings.** Unpublished draft supplied by author.

Lopushinsky, W.; Beebe, T. 1976. **Effects of black poly mulch on survival of Douglas-fir seedlings.** Tree Planters' Notes 71: 7-8.

Main, Marty, Environmental Consultant, Ashland, OR. [Personal communication with Ole Helgerson]. Spring 1985.

Major, Jack. 1977. **California climate in relation to vegetation.** In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley and Sons; 11-74.

Mathews, Ed. 1983. **Paper collars.** In: Proceedings 4th annual forest vegetation management conference; 1982 November 3-4; Eureka, CA. Redding, CA: Forest Vegetation Management Conference; 56-57.

McDonald, Philip M. 1978. **Silviculture-ecology of three native California hardwoods on high sites in north central California.** Corvallis, OR: Oregon State University; 309 p. Ph.D. dissertation.

McDonald, Philip M.; Fiddler, Gary O. 1986. **Release of Douglas-fir seedlings: growth and treatment costs.** Res. Paper PSW-182. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 9 p.

McDonald, Philip M., Fiddler, Gary O.; Smith, William H. 1989. **Mulches and manual release fail to enhance Douglas-fir seedling survival and growth.** In: Proceedings 10th annual forest vegetation management conference; 1988 November 1-3; Eureka, CA. Redding, CA: Forest Vegetation Management Conference; 140-153.

McDonald, Philip M.; Tappeiner, John C., II. 1986. **Weeds: life cycles suggest controls.** Journal of Forestry 84(10): 33-37.

McHenry, W.B.; Willoughby, B.L.; Anderson, D.R.; Roncoroni, J.A.; Smith, N.L.; Standiford, R. 1988. **Comparison of a paper weed smothering mat with atrazine and hexazinone for the control of seedling deerbrush ceanothus, *Ceanothus integerrimus*.** In: Proceedings 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 151-156.

McNabb, David H., Research Forester, Forestry Intensified Research Program, Medford, OR. [Personal communication with Philip M. McDonald]. Summer 1985.

Melton, Lisa. 1989. **Soil surface effects on soil water, soil temperature and Douglas-fir seedling injury following radiation frost damage events.** Corvallis: Oregon State University; 83 p. M.S. thesis.

Minore, D.; Graham, J.N.; Murray, E.W. 1984. **Environment and forest regeneration in the Illinois Valley area of southwestern Oregon.** Res. Note PNW-413. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 20 p.

Newton, Michael. 1961. **Mulch papers for improving plantation survival.** Unpublished draft supplied to author.

Overhulser, J.L. 1955. **Sawdust mulches for larger crops, better soils.** Report No. G-5. Corvallis: Forest Products Laboratory, Oregon State College; 4 p.

Potter, Donald A. 1985. **Control of bearclover.** In: Proceedings 6th annual forest vegetation management conference; 1984 November 1-2; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 144-150.

Rietveld, W.J., Heidmann, L.J. 1974. **Mulching planted ponderosa pine seedlings in Arizona gives mixed results.** Res. Note RM-257. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 3 p.

Roberts, A.N.; Mellenthin, W.M. 1959. **Effects of sawdust mulches. II.** Horticultural crops. Tech. Bull. 50. Corvallis: Agricultural Experiment Station, Oregon State College; 33 p.

Rosenberg, N.J. 1974. **Microclimate: the biological environment.** New York: Wiley Interscience; 315 p.

Roy, D.F. 1955. **Hardwood sprout measurements in northwestern California.** Res. Note PSW-95. Berkeley, CA: California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 6 p.

Sallander, Charles, Forestry Technician, Siskiyou National Forest, Brookings, OR. [Telephone conversation with Philip M. McDonald]. March 1989.

Schaefer-Jones, Gail, Forester, Bureau of Land Management, Roseburg District, Roseburg, OR. [Telephone conversation with Ole Helgerson]. March 1989.

Shumway, S.E. 1981. **Climate.** In: Heilman, P.E.; Anderson, H.W.; Baumgartner, D.M., compilers. Forest soils of the Douglas-fir region. Pullman, WA: Cooperative Extension Service, Washington State University; 87-92.

Spomer, G.G. 1973. **The concept of "interaction" and "operational environment" in environmental analysis.** Ecology 54: 200-204.

Sultan, M.I.; Akhtar A.; Khan, M.S. 1986. **Water use efficiency of *Populus euramericana*.** Pakistan Journal of Forestry 36(2): 53-58.

Tappeiner, John C., II, Professor of Silviculture, College of Forestry, Oregon State University, Corvallis. [Telephone conversation with Philip M. McDonald]. March 1989.

Tappeiner, John C., II; Harrington, Timothy B.; Walstad, John D. 1984. **Predicting recovery of tanoak *(Lithocarpus densiflorus)* and Pacific madrone *(Arbutus menziesii)* after cutting or burning.** Weed Science 32: 413-417.

Trevisan, David, Silviculturist, Shasta-Trinity National Forests. Mt. Shasta, CA. [Telephone conversation with Philip M. McDonald]. March 1989.

Tung, Chao-Hsiung; Batdorff, Jim; DeYoe, David R. 1986. **Survival and growth of Douglas-fir seedlings with spot-spraying, mulching, and root-dipping.** Western Journal of Applied Forestry 1: 108-111.

Waggoner, Paul E.; Miller, Patrick M.; De Roo, Henry C. 1960. **Plastic mulching—principles and benefits.** Bull. No. 634. New Haven: Connecticut Agricultural Experiment Station; 44 p.

Weatherspoon, C. Phillip. 1988. **Preharvest prescribed burning for vegetation management: effects on *Ceanothus velutinus* seeds in duff and soil.** In: Proceedings 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 125-141.

White, D.E.; Newton, M. 1989. **Competitive interactions of whiteleaf manzanita, herbs, Douglas-fir, and ponderosa pine in southwest Oregon.** Canadian Journal of Forest Research 19: 232-238.

Whittaker, R.H. 1960. **Vegetation of the Siskiyou Mountains, Oregon and California.** Ecological Monographs 30(3): 279-332.

Winterbottom, Robert; Hazlewood, Peter T. 1987. **Agroforestry and sustainable development: making the connection.** Ambio 16: 100-110.

The Forest Service, U. S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Research Station

- Represents the research branch of the Forest Service in California, Hawaii, American Samoa and the western Pacific.